R-3896-1

TECHNICAL MANUAL

ENGINE DATA

F-1 ROCKET ENGINE

(ROCKETDYNE)

(NASA-CR-143972) F-1 ROCKET ENGINE DATA MANUAL (Rocketdyne) 233 p N75-76409

Unclas
00/98 42669

CHANGE NOTICE LATEST CHA[illegible] [illegible]AGES [illegible]
THE SAME PAGE[illegible] [illegible]
[illegible] change pages [illegible]
publication. Destroy supers[illegible]

PUBLISHED UNDER AUTHORITY OF THE NATION[illegible] [illegible]ERONAUTICS AND SPAC[illegible]

[illegible] MARCH 1967
CHANGE N[illegible] 12 — 12 MAY 1972

3-[illegible]. ENGINE TEST INSTRUMENTATION.

3-[illegible]. A list of the available engine instrumentation taps is presented in figure 3-46. Selection of instrumentation to determine engine operation and performance during static tests shall be a customer requirement. Recommended instrument range and instrument precision is also shown in figure 3-46. Refer to section II for instrumentation tap locations.

Parameter (Pressure)	Range (psig)	Precision (Percent)	Tap	Recording (Low)	Frequency (High)
LOX Pump Inlet(a)(b)	0-200		[illegible]		X
LOX Pump Inlet(c)	0-200	±0.50	[illegible]	X	
No. 1 LOX Pump Discharge	0-2,000	±0.50	[illegible]	X	
No. 2 LOX Pump Discharge	0-2,000	±0.50	[illegible]	X	
No. 1 LOX Pump Discharge(a)(b)	0-2,000		PO2d-1		X
No. 2 LOX Pump Discharge(a)(b)	0-2,000		PO2e-2		X
No. 1 Main LOX Valve Inlet	0-2,000	±1.00	PO3-1	X	
No. 2 Main LOX Valve Inlet	0-2,000	±1.00	PO3-2	X	
GG LOX Valve Inlet	0-2,000	±1.00	GO1a	X	
GG LOX Valve Inlet(a)	0-2,500		GO1b	X	
GG LOX Injection(a)	0-1,500	±1.00	GO2a	X	
LOX Pump Seal Cavity	0-25	±1.00	PO7b	X	
No. 1 LOX Dome Inlet	0-2,000	±1.00	CO1b-1	X	
No. 2 LOX Dome Inlet	0-2,000	±1.00	CO1b-2	X	
LOX Injection	0-2,000	±1.00	CO3c	X	
LOX Injection(a)(b)	0-2,000		CO3a		X
Heat Exchanger LOX Inlet	0-2,000	±1.00	HO1c	X	
Heat Exchanger GOX Outlet	0-2,000	±1.00	HO4c	X	
No. 1 Fuel Pump Inlet(c)	0-200	±0.50	[illegible]	X	
No. 1 Fuel Pump Inlet(a)(b)	0-200		KF7a-[illegible]		X
No. 2 Fuel Pump Inlet(c)	0-200	±0.50	KF6d-2	X	
No. 1 Fuel Pump Discharge	0-2,500	±0.50	PF2b-1	X	
No. 1 Fuel Pump Discharge(a)(b)	0-2,500		PF2d-1		X
No. 1 Fuel Pump Discharge	0-2,500		PF2c-1	X	
No. 2 Fuel Pump Discharge	0-2,500	±0.50	PF2b-2	X	
No. 2 Fuel Pump Discharge(a)(b)	0-2,500		PF2c-2		X
No. 1 Main Fuel Valve Inlet	0-2,500	±1.00	PF3a-1	X	
No. 2 Main Fuel Valve Inlet	0-2,500	±1.00	PF3a-2	X	
Fuel Manifold	0-2,000	±1.00	CF1c	X	
Fuel Manifold(a)(b)	0-2,000		CF1b		X
Fuel Injection	0-2,000	±1.00	CF2c	X	
Fuel Injection(a)(b)	0-2,000		CF2a		X
Fuel Impeller Backcasing	0-1,000	±1.00	PF10	X	
GG Fuel Valve Inlet	0-2,000	±1.00	GF1	X	
GG Fuel Injection	0-1,500	±1.00	GF2a	X	
LOX Pump Bearing Jet	0-1,000	±1.00	LB1b	X	
Control System Ground Supply	0-2,500	±1.00	NH0	X	
Control System Supply	0-2,500	±1.00	NH1a	X	
Control System Supply	0-2,500		NH1b	X	

(a) Engine-mounted transducer.
(b) All high-frequency pressure instrumentation must have a range of dc to 10 kc ±2 db.
(c) Mount transducers on facility at pump inlet level within ±1 foot.

Figure 3-46. Engine Instrumentation Parameters (Sheet 1 of 3)

Parameter (Pressure)	Range (psig)	Precision (Percent)	Tap	Recording (Low)	Frequency (High)
Engine Control Closing	0-2,500	±1.00	NH2b	X	
Engine Control Opening	0-2,500	±1.00	NH3b	X	
Common Hydraulic Return	0-500	±2.00	NH5b	X	
Common Hydraulic Return	0-500		NH5a	X	
[illegible] Valve Inlet	0-2,500		IF2	X	
[illegible] Container Inlet	0-2,500		IF3	X	
Combustion Chamber(a)(b)	0-3,600		CG1a		X
Combustion Chamber	0-1,500	[illegible]	CG1b	X	
[illegible]	0-1,500		CG1d	X	
GG Chamber(a)(b)	0-1,500		GG1c		X
GG Chamber	0-1,500	[illegible]	GG1b	X	
Turbine [illegible]	0-1,500	[illegible]	GG2a	X	
Turbine [illegible]	0-100	[illegible]	TG3a	X	
LOX [illegible]	0-200	[illegible]	CCP	X	
GG [illegible]	0-500	[illegible]	CCP	X	
LOX [illegible]	0-1,500	[illegible]	CCP	X	
Heat [illegible]	0-500	±1.00	HH2c	X	
Heat [illegible] Helium [illegible]	0-500	±1.00	HH3c	X	
Parameter (Temperature)	**Range (°F)**				
Heat Exchanger GOX Outlet	0-1,000	±1.00	HO3	X	
Heat Exchanger Return [illegible]	0-500	±1.00	NH4	X	
Turbine [illegible](e)	0-2,000	±1.00	GG2b	X	
Turbine Inlet (Manifold)(e)	0-2,000	±1.00	[illegible]	X	
Turbine [illegible](e)	0-2,000	±1.00	TG3b	X	
Heat Exchanger LOX Inlet(f)	-300 to -250	±1.00	HO2	X	
Parameter (Acceleration)	**Range (g rms)**				
LOX [illegible] Inlet Flange(g)	0-250		PZA1-Y(h)		X
LOX [illegible] Pos. 10(i)	0-707		CZA10-Y(h)		X
LOX [illegible] Pos. 4(i)	0-707		CZA4-Y(h)		X
Elbow to Inlet Flange Fuel Pump No. 1 Side(g)(j)	0-250		PZA2-Y(h)		X
Elbow to Inlet Flange Fuel Pump No. 1 Side(g)	0-250		PZA3-Z		X

(a) [illegible] mounted transducer.
(b) All high-frequency pressure instrumentation must have a range of dc to 10 kc ±2 db.
(c) On engines not incorporating MD70 or MD83 change.
(e) Thermocouple R452[illegible] gage must be immersed to one-inch depth, which is defined as the [illegible] distance from inside wall of component at point of thermocouple insertion to thermocouple junction.
(f) Heat exchanger oxidizer inlet temperature bulb must be immersed 0.75 ±0.5 inch. (Refer to footnote e.)
(g) 0-2,500 cps low-pass filter.
(h) Centerline of tapped hole is approximately parallel to y-axis.
(i) 0-10,000 cps low-pass filter.
(j) Tri-axial mounting pad.

Figure 3-46. Engine Instrumentation Parameters (Sheet 2 of 3)

Parameter (Acceleration)	Range (g rms)	Precision (Percent)	Tap	Recording Frequency (Low)	Recording Frequency (High)
Boss of Fuel Pump Housing(g)(l)	0-250		PZA8-Z(h)		X
Boss of Fuel Pump Housing(g)	0-250		PZA9-Z(k)		X
LOX Dome Pos. 7(j)	0-250		CZA7-X(k)		X
Gas Generator Combustor(g)(l)	0-500		Y-Axis Adapter Block(h)		X
Gas Generator Combustor(g)(l)	0-500		Z-Axis Adapter Block(m)		X
LOX Dome Pos. 1(i)	0-707		CZA1-Y(h)		
LOX Dome Pos. 2(i)	0-250		CZA2-Y(h)		X

(g) 0-3,500 cps low-pass filter.
(h) Centerline of tapped hole is approximately parallel to y-axis.
(i) 0-10,000 cps low-pass filter.
(j) Tri-axial mounting pad.
(k) Centerline of tapped hole is approximately parallel to x-axis.
(l) Adapter 88-[illegible] and bolt 88-702385-3, or equivalent, must be [illegible] in conjunction with the gas generator acceleration instrumentation.
(m) Centerline of tapped hole is approximately parallel to z-axis.

Figure 3-46. Engine Instrumentation Parameters (Sheet 8 of 8)

MANUAL DATA SUPPLEMENTS

Manual Data Supplements are issued from time to time to communicate important and urgent information concerning the equipment covered in this manual. These Supplements bear an identifying number and should be filed in this Appendix.

Manual Data Supplements directly affect the data in this manual and will be incorporated into this manual during a future updating effort.

A Supplement Record is issued periodically to indicate the status of Supplements issued for this manual. The status of each Supplement is indicated in the "Supplement Status" column. For active Supplements, no status is entered. For incorporated Supplements, "Incorporated" is entered.

Upon receipt of a Manual Data Supplement, make an appropriate reference to the Supplement in the margin next to the data supplemented. Supplements that have been incorporated into this manual shall be discarded.

MANUAL DATA SUPPLEMENTS

Manual Data Supplements are issued from time to time to communicate important and urgent information concerning the equipment covered in this manual. These Supplements bear an identifying number and should be filed in this Appendix.

Manual Data Supplements directly affect the data in this manual and will be incorporated into this manual during a future updating effort.

A Supplement Record is issued periodically to indicate the status of Supplements issued for this manual. The status of each Supplement is indicated in the "Supplement Status" column. For active Supplements, no status is entered. For incorporated Supplements, "Incorporated" is entered.

Upon receipt of a Manual Data Supplement, make an appropriate reference to the Supplement in the margin next to the data supplemented. Supplements that have been incorporated into this manual shall be discarded.

MANUAL DATA SUPPLEMENT RECORD

This Supplement Record indicates the status of Supplements issued for Technical Manual R-3896-1 as of the date specified above. Supplements which have been incorporated into the manual shall be removed from the Appendix and destroyed. This Supplement Record supersedes Supplement Record dated 14 June 1966.

Supplement Number	Dated	Description	Supplement Status
R-3896-1-1	14 June 1966	Changes methods of determining heat exchanger oxidizer and helium bypass orifice sizes.	Incorporated
R-3896-1-2	30 June 1966	Corrects stage condition fuel and oxidizer inlet pressure requirements for predicting engine start times, and corrects equation used to predict time from engine control valve start signal to hypergol switch dropout.	Incorporated
R-3896-1-3	9 June 1971	Changes the description of the engine envelope dimensions and the engine dry weight to be compatible with data presented in section II.	Incorporated

3-40. CALCULATIONS INVOLVING A TYPICAL ENGINE.

3-41. For calculations involving a typical engine, the initial values would be the same as the nominal values, as follows:

$$F_{E_i} = F_{E_N} \qquad P_{a_i} = P_{a_N} \qquad T_{F_i} = T_{F_N}$$

$$\rho_{F_i} = \rho_{F_N} \qquad \rho_{O_i} = \rho_{O_N}$$

$$P_{F_i} = P_{F_N} \qquad P_{O_i} = P_{O_N}$$

The following are the calculations used to determine the thrust of the engine when operated under the following conditions:

a.	Atmospheric pressure	=	3.90 psia
b.	Fuel temperature	=	75° F
c.	Fuel density	=	50.45 lb/cu ft
d.	Oxidizer density	=	70.90 lb/cu ft
e.	Fuel pump inlet pressure	=	42.00 psia
f.	Oxidizer pump inlet pressure	=	89.55

$$\frac{F_E - 1,522,000}{1,522,000} = \frac{3.90 - 14.696}{14.696}(-0.1458) + \left(\frac{75.00 - 60.00}{60.00}\right)(0.0191) + \left(\frac{50.45 - 50.45}{50.45}\right)(-0.9434) + \left(\frac{70.90 - 71.38}{71.38}\right)(2.1345) + \left(\frac{42.00 - 45.00}{45.00}\right)(-0.0090) + \left(\frac{89.55 - 65.00}{65.00}\right)(0.0544)$$

$$\frac{F_E - 1,522,000}{1,522,000} = (-0.7346)(-0.1458) + (0.2500)(0.0191) + (0.0\quad)(-0.9434) + (-0.0067)(2,1345) + (-0.0667)(0.0090) + (0.3777)(0.0544)$$

$$= +0.1187 \text{ or } +11.87 \text{ percent change}$$

$$F_E = +0.1187\,(1,522,000) + 1,522,000$$

$$= +180,700 + 1,522,000 = 1,702,700$$

The incremental thrust has been found to be 180,700 lb for the conditions stated, yielding a final engine thrust of 1,702,700 lb. Propellant densities may be estimated from measured temperature and pressure data with the aid of figures 3-40 and 3-41. Figure 3-40 presents the relationship between the temperature and density for a nominal cut of RP-1 fuel. When the density of a batch of RP-1 is known at one temperature, the density at another temperature can be determined with the slope of the nominal RP-1 line shown in figure 3-40. The effect of pressure on the density of RP-1 is small and may be ignored for inlet conditions encountered on the engine. Figure 3-41 presents the relationship between liquid oxygen temperature, pressure, and density. Two density-versus-temperature curves are presented to show the effect of varying inlet pressure on oxygen density.

3-42. CALCULATIONS INVOLVING A SPECIFIC ENGINE.

3-43. When the values of actual engine parameters differ from those used as nominal values in the table of influence coefficients, the "delta method" of application of influence coefficients is used. This procedure consists of computing an incremental change of variables rather than a percentage change of these variables. The incremental change is then applied to the actual engine value. This effect can be accomplished by using the equation of the quantities

$$F_{E_i},\ P_{a_i},\ F_i,\ \rho_{O_i},\ P_{F_i},\ \text{and } P_{O_i},$$

which are defined as the actual engine values of these parameters. All other quantities are as defined previously.

3-43A. TEST TREND CORRECTIONS.

3-43B. During a test, the engine exhibits characteristic trends that may be predicted with the use of influence coefficients. Nominal and actual performance values are established during a time interval of 35-38 seconds of burn time. Changes occur in turbine operational characteristics resulting from coke deposits on internal turbine assembly. Performance changes are calculated for burn time using figures 3-41A and 3-41B for engines F-2029 through F-2065 and figures 3-44 and 3-44A for engines F-2066 and subsequent. Figures 3-41A and 3-44 present the percentage change in turbine nozzle area as a

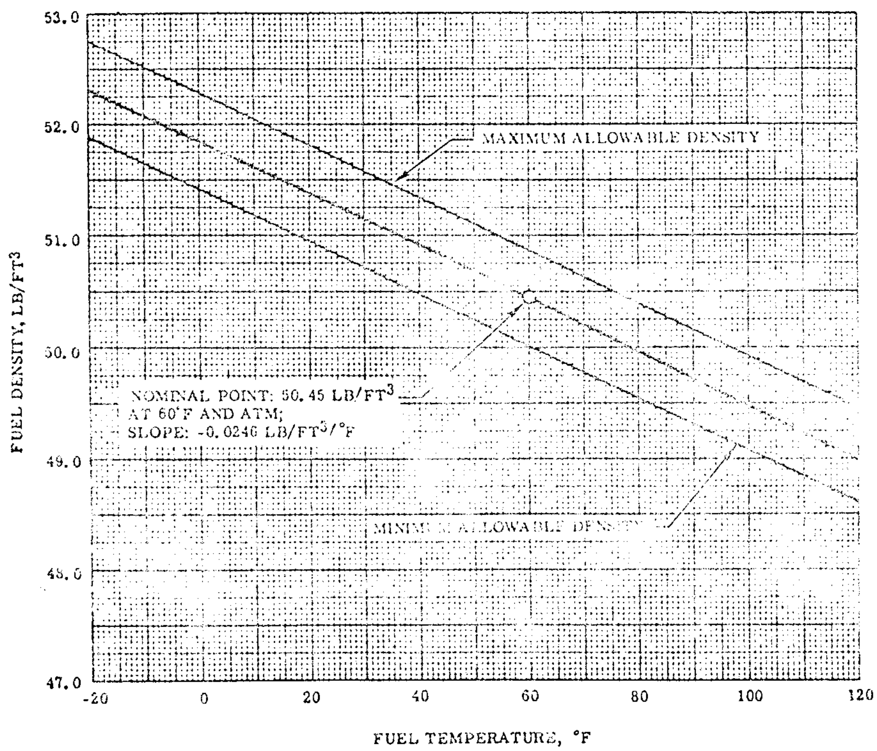


Figure 3-40. RP-1 Fuel Density Versus Temperature

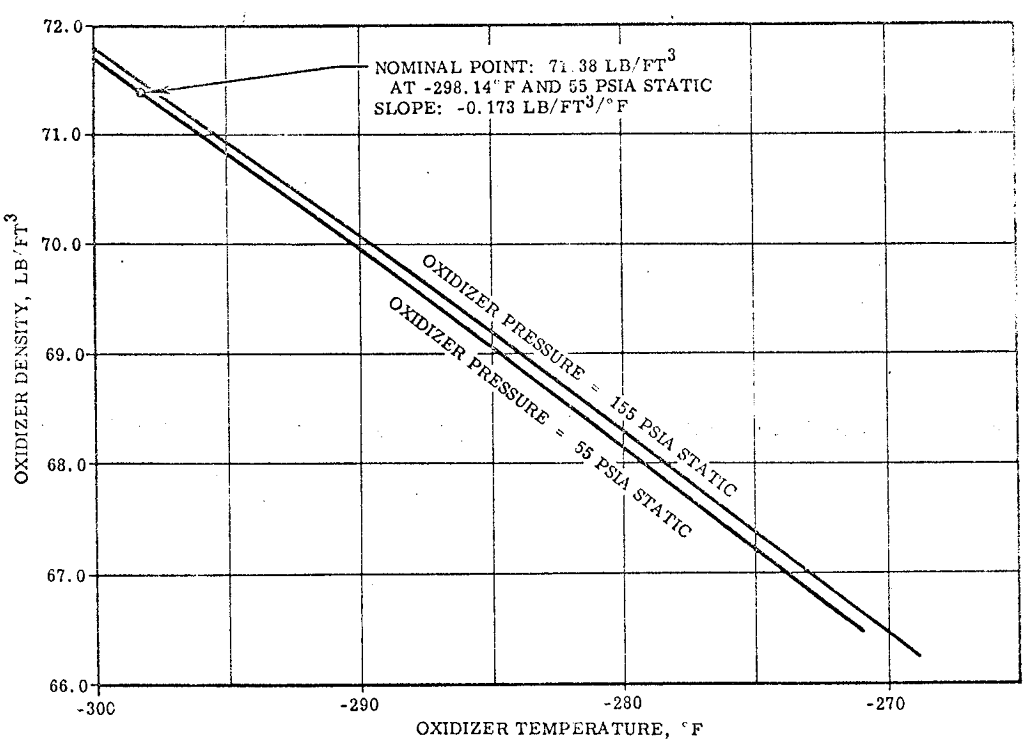


Figure 3-41. Oxidizer Density Versus Temperature

function of burn time, and figures 3-41B and 3-44A present the percentage change in turbine efficiency ratio as a function of burn time. Performance parameters for burn time are adjusted by obtaining the percentage changes expected at the burn time of interest. These percentage changes and the parameter influence coefficients are then multiplied to determine the net percentage change in the performance parameter of interest. In the following example, the thrust of the engine operated under the conditions specified in paragraph 3-41A is adjusted to a 90-second burn time. In figure 3-41A the percentage change in turbine nozzle area at 90 seconds is -3.0 percent. In figure 3-41B the percentage change in turbine efficiency ratio at 90 seconds is -0.25 percent. Therefore, using influence coefficients (figure 3-39),

$$\frac{F_E - 1{,}702{,}700}{1{,}522{,}000} = \begin{matrix}(-0.0300)\ (0.0972) \\ (-0.0025)\ (1.1725)\end{matrix} +$$

$$= -0.00585$$

$$F_E = (-0.00585)\ (1{,}522{,}000) + 1{,}702{,}700$$

$$= -8{,}904 + 1{,}702{,}700$$

$$= 1{,}693{,}796 \text{ lb}$$

Figures 3-41C and 3-44B present thrust differential (based on a predicted performance value from a data slice between 35 and 38 seconds flight time at sea-level and turbopump inlet standard conditions) versus burn time when the performance values are adjusted using influence coefficients from column 11 and 12 of figures 3-39 or 3-43 and turbine nozzle area and turbine efficiency ratio changes from figures 3-41A and 3-41B or 3-44 and 3-44A.

3-44. NONLINEAR CORRECTIONS

3-45. A special computational procedure has been devised to extend the usefulness of engine influence coefficient. This technique is used to allow nonlinear corrections to be made for parameters where the linear approximation is not sufficiently accurate. An example of this method is the C* (characteristic velocity) correction. In this case, a plot of C* correction versus the change in engine mixture ratio is included in addition to the table of influence coefficients. A plot of these parameters for the engine is shown in figures 3-42 and 3-44C. The change in engine mixture ratio is computed for the changes in atmospheric pressure, propellant densities, etc, and with the assumption that the C* correction is zero. With this change in engine mixture ratio, the C* correction is read from the curve. This value of C* correction is used with the other independent variables to recompute the engine mixture ratio, which yields a new value of C* correction. The mixture ratio is then recomputed using the last value of C* correction. This iterative process is continued until the computed mixture ratio ceases to change between two iterations. The corresponding value of C* correction is then used with the other independent variables to compute the changes in the remaining dependent variables. For example, if the final iteration change in engine mixture ratio accompanying the 11.87-percent thrust change in the preceding example were -5 percent, then the C* correction from figure 3-42 is 0.10 percent. Therefore, the true change in engine thrust is $F_E = 11.87 + 1.1319\ (-0.10) = +11.76$ percent.

3-46. COMPONENT REPLACEMENT EFFECTS ON ENGINE PERFORMANCE AT SEA LEVEL.

3-47. Component replacement effects on engine performance at sea level are in R-3896-11. The deviations presented are the maximum expected effects on sea-level engine thrust, mixture ratio, and specific impulse when the listed components are replaced, and are applicable to engines as noted. The following procedure is to be used for determining the maximum expected performance deviations for individual engines.

a. The deviations listed in R-3896-11, corresponding to hardware replaced on the engine, are to be tabulated and included with the Engine Log Book. This tabulation is necessary for future reference and continuous updating when additional replacements are made.

b. The combination of deviations due to the replacement of each individual component determines the expected maximum performance deviation. The combination is accomplished by calculating the square root of the sum of the squares of the deviations listed in R-3896-11, corresponding to each component replaced. Components replaced a second time are treated as a single replacement of the item. (No additional variation is added besides the variation for the component being replaced a second time.) An example is shown in figure 3-45.

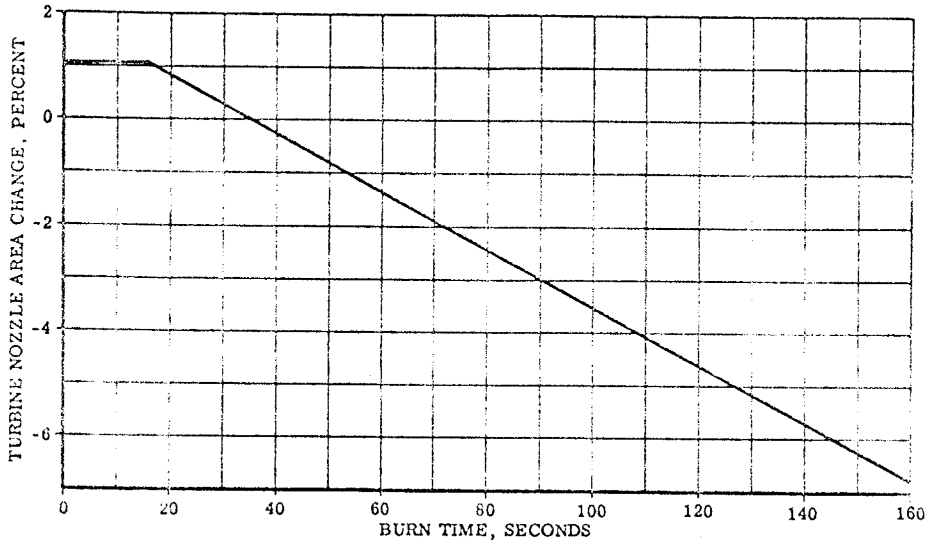


Figure 3-41A. Turbine Nozzle Area Change Versus Burn Time (Engines F-2029 Through F-2065)

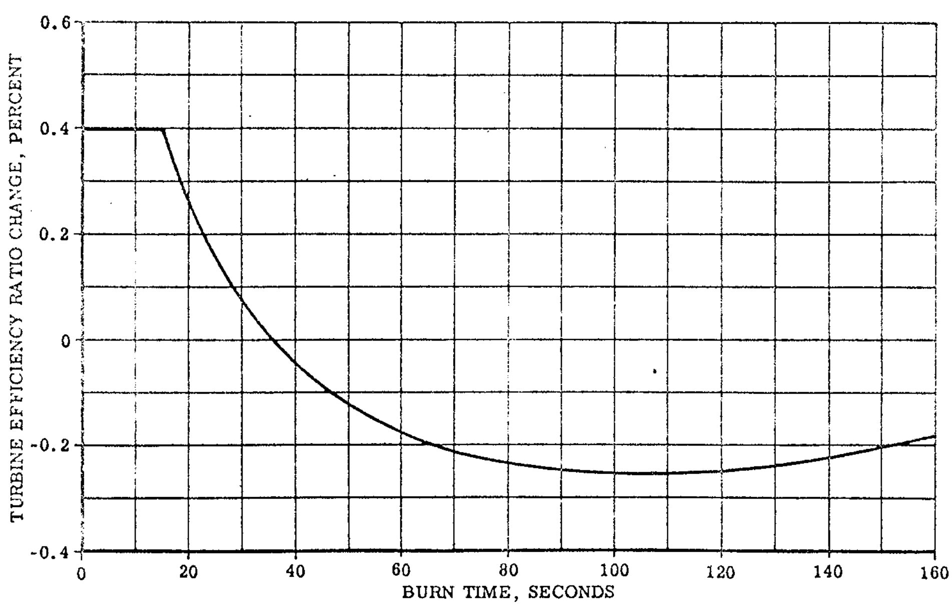


Figure 3-41B. Turbine Efficiency Ratio Curve Change Versus Burn Time (Engines F-2029 Through F-2065)

function of burn time, and figure 3-41B presents the percentage change in turbine efficiency ratio as a function of burn time. Performance parameters for burn time are adjusted by obtaining from figures 3-41A and 3-41B the percentage changes expected at the burn time of interest. These percentage changes and the parameter influence coefficients are then multiplied to determine the net percentage change in the performance parameter of interest. In the following example, the thrust of the engine operated under the conditions specified in paragraph 3-41A is adjusted to a 90-second burn time. In figure 3-41A the percentage change in turbine nozzle area at 90 seconds is -3.0 percent. In figure 3-41B the percentage change in turbine efficiency ratio at 90 seconds is -0.25 percent. Therefore, using influence coefficients (figure 3-39),

$$\frac{F_E - 1{,}702{,}700}{1{,}522{,}000} = (-0.0300)\ (0.0972) + (-0.0025)\ (1.1725)$$

$$= -0.00585$$

$$F_E = (-0.00585)\ (1{,}522{,}000) + 1{,}702{,}700$$

$$= -8{,}904 + 1{,}702{,}700$$

$$= 1{,}693{,}796 \text{ lb}$$

Figure 3-41C presents thrust differential (based on a predicted performance value from a data slice between 35 and 38 seconds flight time at sea-level and turbopump inlet standard conditions) versus burn time when the performance values are adjusted using influence coefficients from column 11 and 12 of figure 3-39 and turbine nozzle area and turbine efficiency ratio changes from figures 3-41A and 3-41B.

3-44. NONLINEAR CORRECTIONS.

3-45. A special computational procedure has been devised to extend the usefulness of engine influence coefficient. This technique is used to allow nonlinear corrections to be made for parameters where the linear approximation is not sufficiently accurate. An example of this method is the C* (characteristic velocity) correction. In this case, a plot of C* correction versus the change in engine mixture ratio is included in addition to the table of influence coefficients. A plot of these parameters for the engine is shown in figure 3-42. The change in engine mixture ratio is computed for the changes in atmospheric pressure, propellant densities, etc, and with the assumption that the C* correction is zero. With this change in engine mixture ratio, the C* correction is read from the curve. This value of C* correction is used with the other independent variables to recompute the engine mixture ratio, which yields a new value of C* correction. The mixture ratio is then recomputed using the last value of C* correction. This iterative process is continued until the computed mixture ratio ceases to change between two iterations. The corresponding value of C* correction is then used with the other independent variables to compute the changes in the remaining dependent variables. For example, if the final iteration change in engine mixture ratio accompanying the 11.87-percent thrust change in the preceding example were -5 percent, then the C* correction from figure 3-42 is 0.10 percent. Therefore, the true change in engine thrust is $F_E = 11.87 + 1.1319\ (-0.10) = +11.76$ percent.

3-46. COMPONENT REPLACEMENT EFFECTS ON ENGINE PERFORMANCE AT SEA LEVEL.

3-47. Component replacement effects on engine performance at sea level are in R-3896-11. The deviations presented are the maximum expected effects on sea-level engine thrust, mixture ratio, and specific impulse when the listed components are replaced, and are applicable to engines as noted. The following procedure is to be used for determining the maximum expected performance deviations for individual engines.

a. The deviations listed in R-3896-11, corresponding to hardware replaced on the engine, are to be tabulated and included with the Engine Log Book. This tabulation is necessary for future reference and continuous updating when additional replacements are made.

b. The combination of deviations due to the replacement of each individual component determines the expected maximum performance deviation. The combination is accomplished by calculating the square root of the sum of the squares of the deviations listed in R-3896-11, corresponding to each component replaced. Components replaced a second time are treated as a single replacement of the item. (No additional variation is added besides the variation for the component being replaced a second time.) An example is shown in figure 3-45.

A ONE PERCENT INCREASE IN ANY ONE OF THE INDEPENDENT VARIABLES CAUSES THE FOLLOWING PERCENTAGE CHANGE IN ANY ONE OF THE DEPENDENT VARIABLES.

-INDEPENDENT VARIABLES-

1- ATMOSPHERIC PRES.	0.14700E 02	5- FUEL PUMP INLET PRES. . . . .
2- FUEL DENSITY (CONSTANT TEMP) . . .	0.10000E 01	6- OXIDE PUMP INLET PRES . . . .
3- FUEL TEMP (CONSTANT DENSITY) . . .	0.60000E 02	7- C* CORRECTION . . . .
4- OXIDIZER DENSITY	0.10000E 01	8- ACCELERATION . . . .

-DEPENDENT VARIABLES-

		1-	2-	3-	4-	5-	6
ENGINE THRUST	0.15220E 07	-0.1464	-0.9062	0.0184	2.0994	-0.0083	0.
ENGINE SPECIFIC IMPULSE	0.26534E 03	-0.1464	-0.1391	0.0027	0.3076	-0.0013	0.
ENGINE MIXTURE RATIO	0.22698E 01	-0.0000	-1.5206	-0.0064	1.5094	-0.0201	0.
ENGINE FUEL FLOW	0.17543E 04	0.0	0.2885	0.0201	0.7440	0.0069	0.
ENGINE OXIDIZER FLOW	0.39818E 04	-0.0000	-1.2321	0.0137	2.2534	-0.0131	0.
TC INJECTOR END PRES	0.11248E 04	0.0	-0.6926	0.0164	1.7325	-0.0059	0.
TC C* ACTUAL	0.54514E 04	0.0000	0.0989	0.0007	-0.0840	0.0014	-0.
GIMBAL SUPPLY PRESSURE	0.18383E 04	-0.0000	-0.5947	0.0259	1.6450	0.0017	0.
GG FUEL FLOW.	0.11795E 03	-0.0000	0.4077	0.0159	0.6122	0.0073	0.
GG OXIDE FLOW	0.49045E 02	0.0000	-0.8182	0.0060	1.8232	-0.0079	0.
TURBINE SPEED	0.54922E 04	-0.0000	-0.7865	0.0111	0.8233	-0.0080	0.
TURBINE EXIT STATIC PRES	0.58273E 02	0.0000	-0.6503	0.0209	1.6968	-0.0059	0.
EXHAUST NOZZLE TOTAL PRES.	0.46852E 02	0.0	-0.4888	0.0191	1.5281	-0.0039	0.
TURBINE MAINFOLD TEMPERATURE. . . .	0.15560E 04	0.0	-2.8035	0.0323	2.9285	-0.0345	0.

Figure 3-43. Engine Influence Coefficients (Predicted) (Engines F-2066 and Subsequent)

. 0.45000E 02 9- MAIN FUEL ORIFICE RESISTANCE 0.31342E-02
. 0.65000E 02 10- GG OXIDIZER ORIFICE RESISTANCE ... 0.77156E 01
. 0.10000E 01 11- TURBINE INLET NOZZLE AREA 0.17023E 02
. 0.10000E 01 12- TURBINE EFFICIENCY MULTIPLIER ... 0.10000E 01

-	7-	8-	9-	10-	11-	12-
545	1.1781	0.0013	-0.0264	-0.2549	0.1254	1.2273
080	1.1544	0.0002	-0.0053	-0.0368	0.0083	0.1749
337	-0.0571	0.0007	0.0690	-0.0085	-0.0076	0.0232
232	0.0633	0.0007	-0.0689	-0.2121	0.1224	1.0362
569	0.0062	0.0013	0.0001	-0.2206	0.1148	1.0595
454	1.0285	0.0011	-0.0278	-0.2219	0.1088	1.0675
018	1.0167	-0.0000	-0.0058	-0.0029	0.0010	0.0130
459	0.6604	0.0012	0.0149	-0.3047	0.1466	1.4607
207	0.3862	0.0007	0.0215	-0.1348	0.3911	0.9808
455	0.5027	0.0013	-0.0124	-0.3093	0.5187	0.9709
234	0.2837	0.0007	-0.0076	-0.1672	0.0841	0.8051
429	0.4931	0.0012	-0.0081	-0.2904	0.5112	0.8618
393	0.4739	0.0012	-0.0037	-0.2657	0.4995	0.8543
612	0.3329	0.0015	-0.0760	-0.4290	0.2032	0.1301

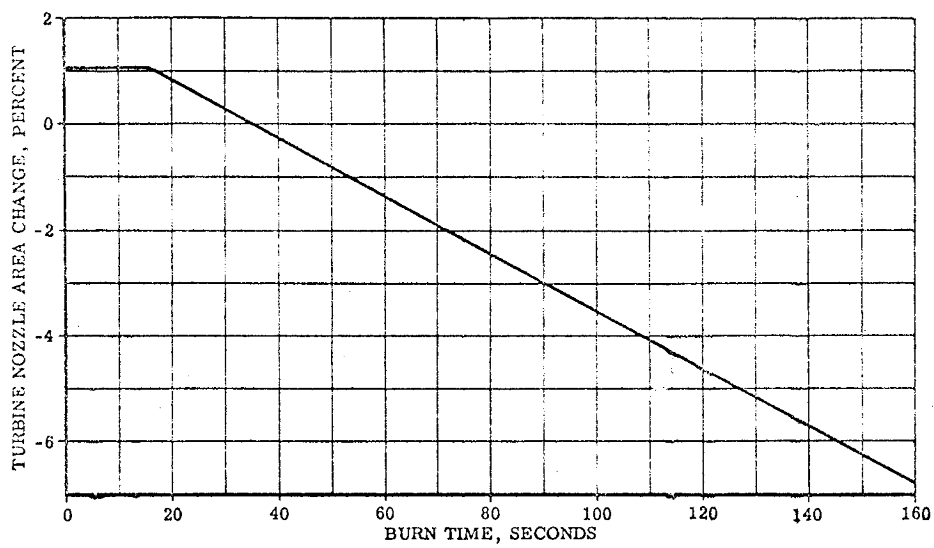


Figure 3-41A. Turbine Nozzle Area Change Versus Burn Time

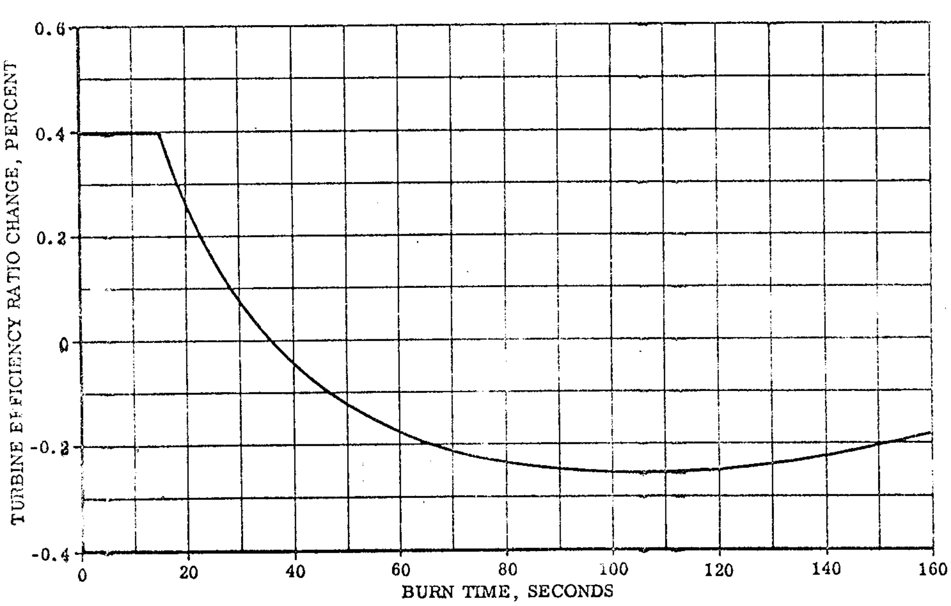


Figure 3-41B. Turbine Efficiency Ratio Curve Change Versus Burn Time

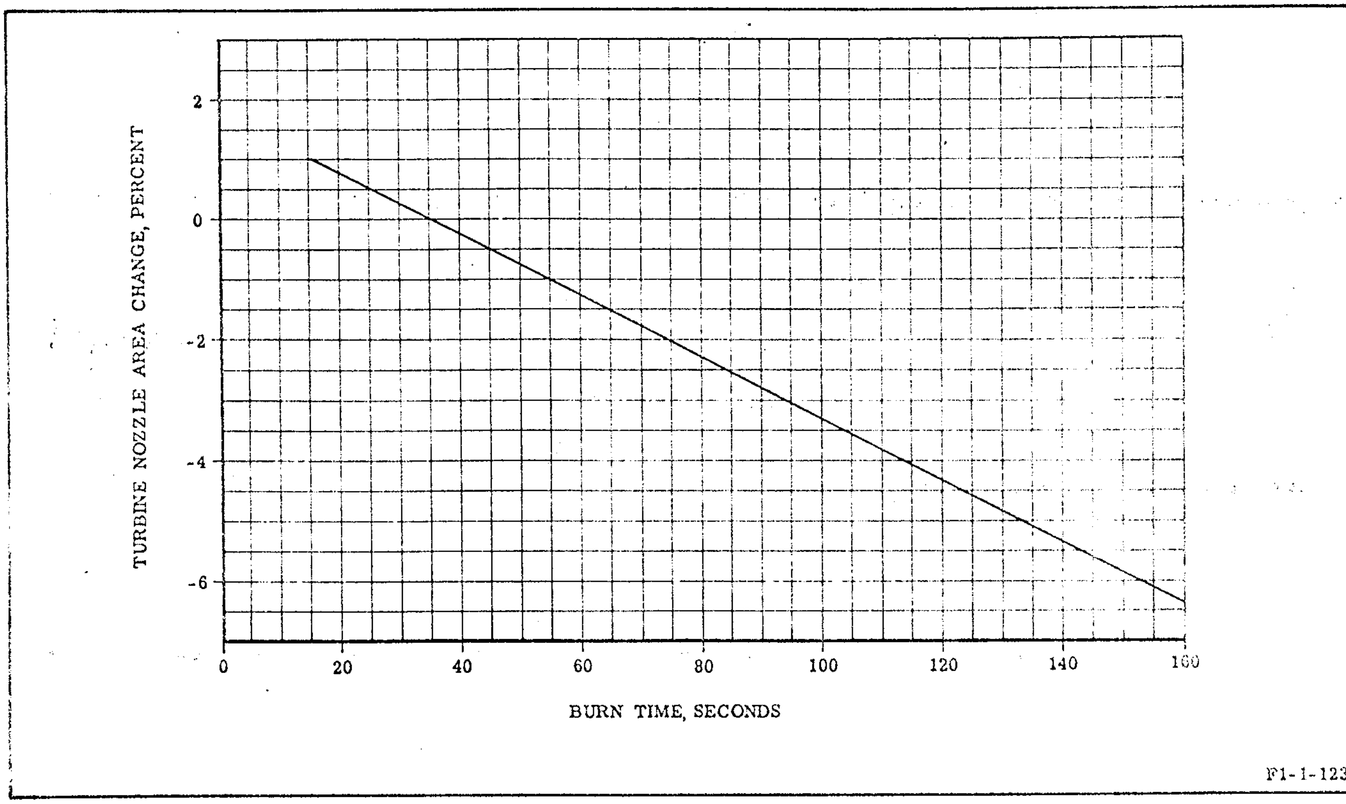


Figure 3-44. Turbine Nozzle Area Change Versus Burn Time (Engines F-2066 and Subsequent)

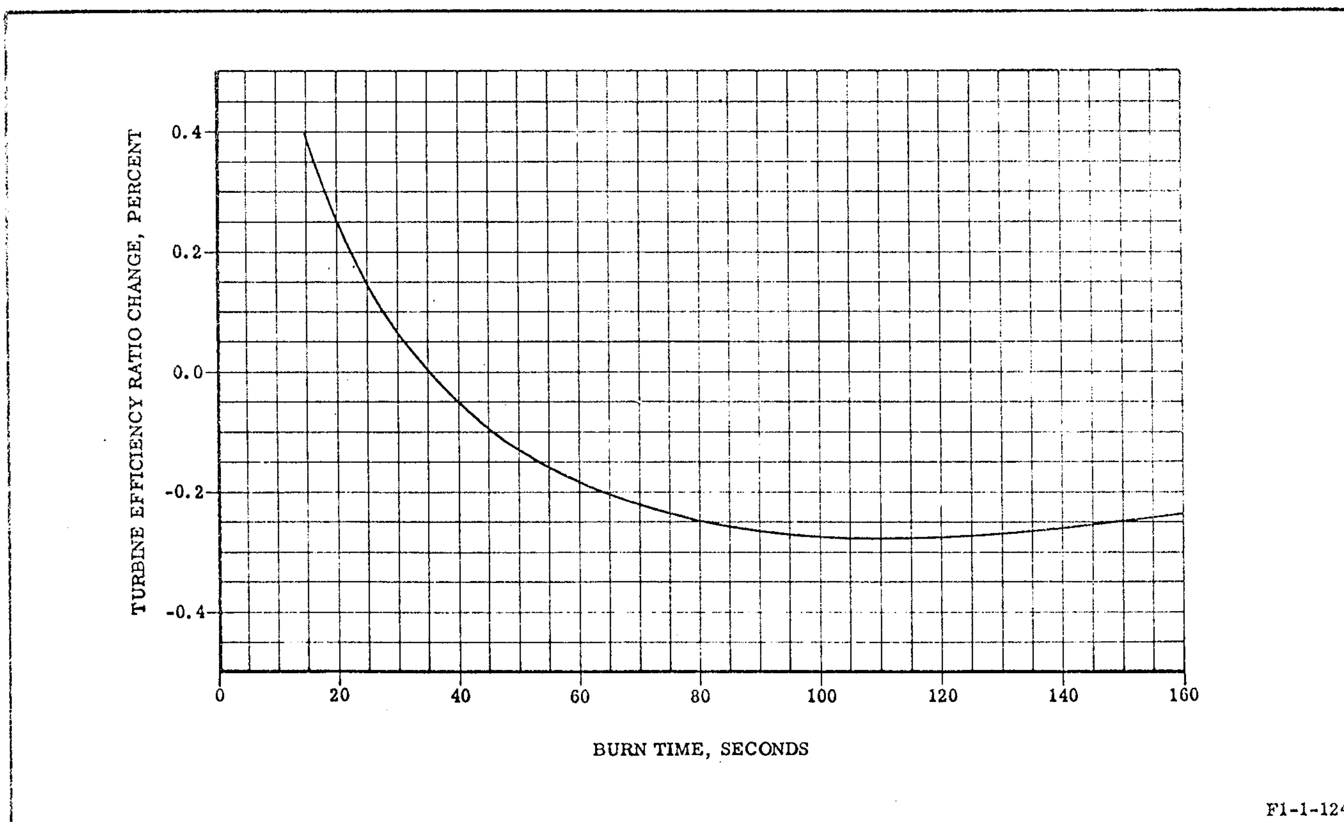


Figure 3-44A. Turbine Efficiency Ratio Curve Change Versus Burn Time (Engines F-2066 and Subsequent)

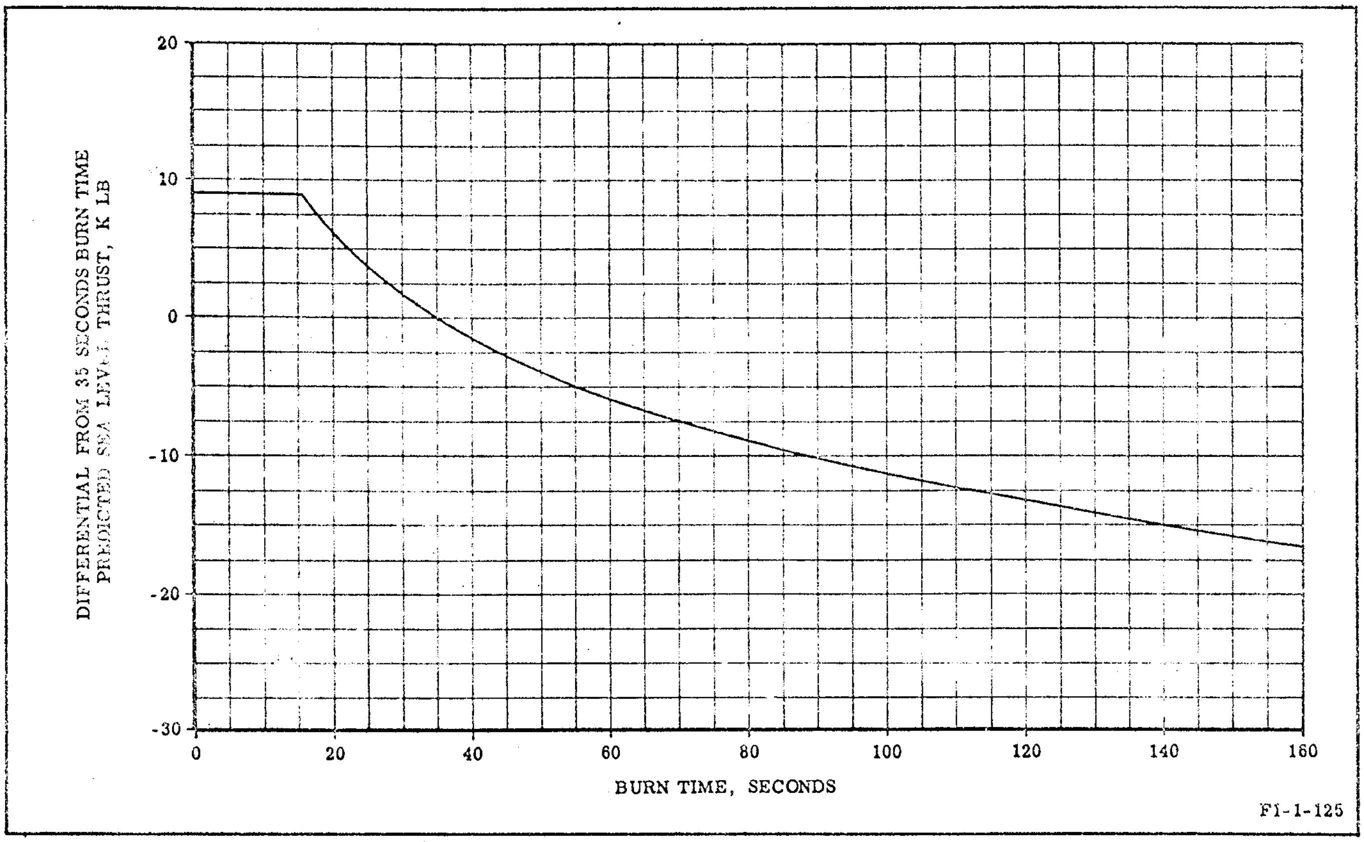


Figure 3-44B. Thrust Trend for Flight Engines (Engines F-2066 and Subsequent)

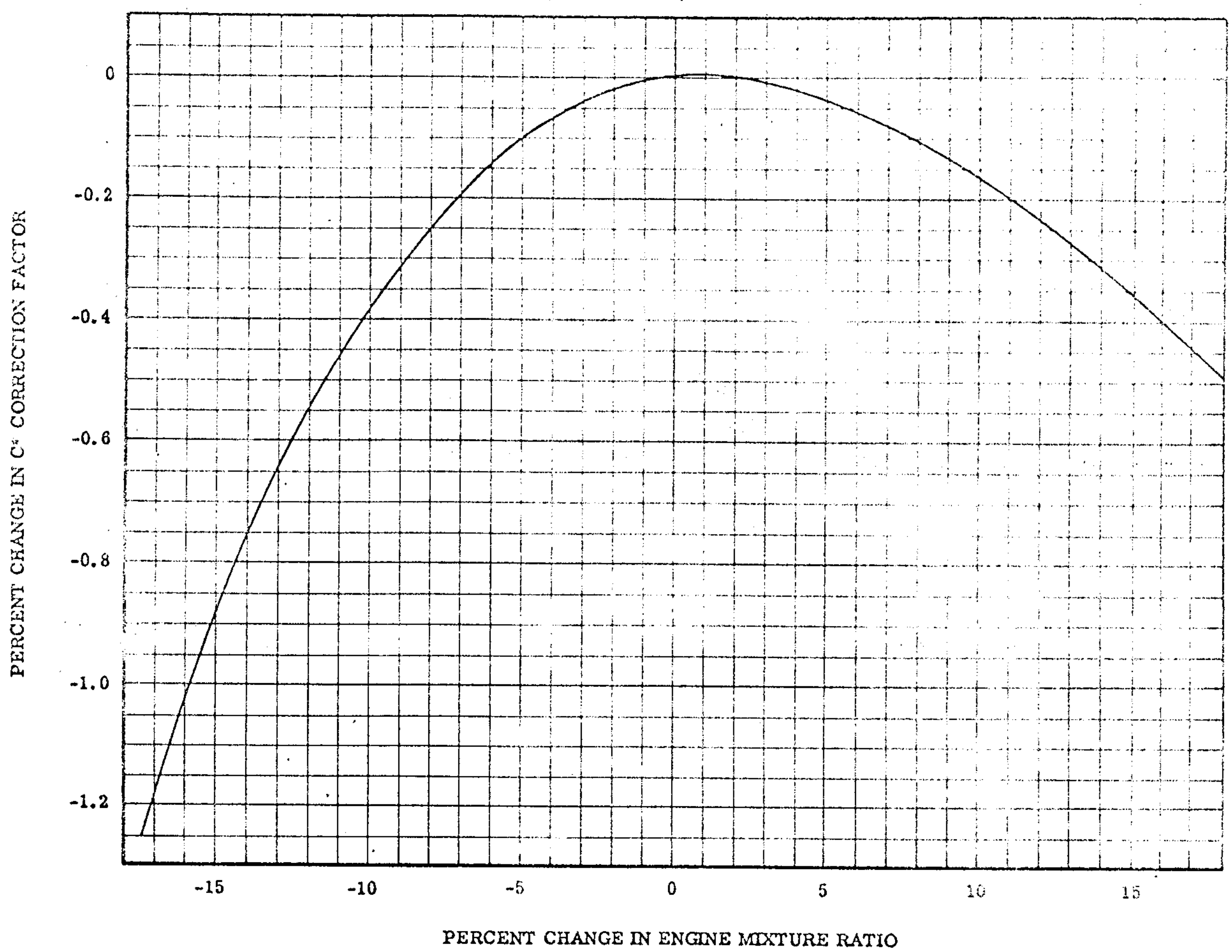


Figure 3-44C. C* Correction Curve (Actual) (Engines F-2066 and Subsequent)

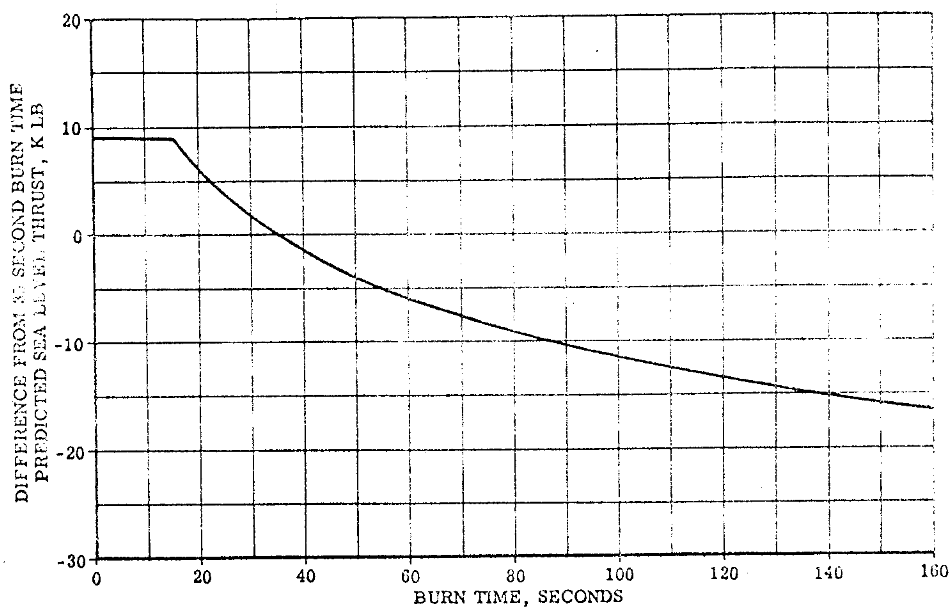
ENGINE XXXX COMPONENT REPLACEMENT LOG

Component Replacement	Thrust Deviation	Mixture Ratio Deviation	Specific Impulse Deviation
No. 1 Fuel Valve	0.9	0.017	0.14
No. 1 Turbopump Fuel Outlet Line	0.3	0.007	0.05
Expected Maximum Deviation as of (Date 1)[d]	$\sqrt{(0.9)^2+(0.3)^2}$ $= 0.9$	$\sqrt{(0.017)^2+(0.007)^2}$ $= 0.018$	$\sqrt{(0.14)^2+(0.05)^2}$ $= 0.15$
No. 1 Turbopump Oxidizer Outlet Line	7.1	0.010	0.14
Expected Maximum Deviation as of (Date 2)[e]	$\sqrt{(0.9)^2+(0.3)^2+(7.1)^2}$ $= 7.2$	$\sqrt{(0.017)^2+(0.007)^2+(0.010)^2}$ $= 0.021$	$\sqrt{(0.14)^2+(0.05)^2+(0.14)^2}$ $= 0.20$
No. 1 Turbopump Fuel Outlet Line	0.3	0.007	0.05
Thrust Chamber Injector	6.5	0.029	0.33
Expected Maximum Deviation as of (Date 3)[f]	$\sqrt{(0.9)^2+(0.3)^2+(7.1)^2+(6.5)^2}$ $= 9.7$	$\sqrt{(0.017)^2+(0.007)^2+(0.010)^2+(0.029)^2}$ $= 0.036$	$\sqrt{(0.14)^2+(0.05)^2+(0.14)^2+(0.33)^2}$ $= 0.39$

(d) First component replacement since delivery (Date 1).
(e) Additional component replaced on (Date 2).
(f) Turbopump fuel outlet line No. 1 replaced second time, also main injector changed on (Date 3).

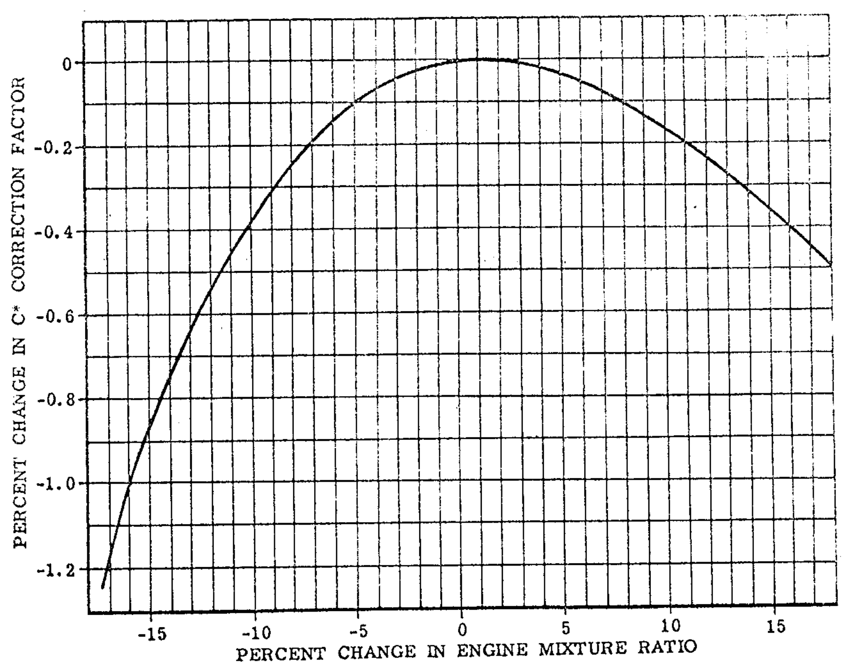
Figure 3-45. Example of Calculations Required to Determine Deviations in Engine Performance Due to Component Replacement

All data on pages 3-47 through 3-54 deleted.



F1-1-121

Figure 3-41C. Thrust Trend for Flight



F1-1-120

Figure 3-42. C* Correction Curve (Actual)

Figures 3-43 and 3-44 deleted.

ENGINE XXXX COMPONENT REPLACEMENT LOG

Component Replacement	Thrust Deviation	Mixture Ratio Deviation	Specific Impulse Deviation
No. 1 Fuel Valve	0.9	0.017	0.14
No. 1 Turbopump Fuel Outlet Line	0.3	0.007	0.05
Expected Maximum Deviation as of (Date 1)(d)	$\sqrt{(0.9)^2+(0.3)^2} = 0.9$	$\sqrt{(0.017)^2+(0.007)^2} = 0.018$	$\sqrt{(0.14)^2+(0.05)^2} = 0.15$
No. 1 Turbopump Oxidizer Outlet Line	7.1	0.010	0.14
Expected Maximum Deviation as of (Date 2)(e)	$\sqrt{(0.9)^2+(0.3)^2+(7.1)^2} = 7.2$	$\sqrt{(0.017)^2+(0.007)^2+(0.010)^2} = 0.021$	$\sqrt{(0.14)^2+(0.05)^2+(0.14)^2} = 0.20$
No. 1 Turbopump Fuel Outlet Line	0.3	0.007	0.05
Thrust Chamber Injector	6.5	0.029	0.33
Expected Maximum Deviation as of (Date 3)(f)	$\sqrt{(0.9)^2+(0.3)^2+(7.1)^2+(6.5)^2} = 9.7$	$\sqrt{(0.017)^2+(0.007)^2+(0.010)^2+(0.029)^2} = 0.036$	$\sqrt{(0.14)^2+(0.05)^2+(0.14)^2+(0.33)^2} = 0.39$

(d) First component replacement since delivery (Date 1).
(e) Additional component replaced on (Date 2).
(f) Turbopump fuel outlet line No. 1 replaced second time, also main injector changed on (Date 3).

Figure 3-45. Example of Calculations Required to Determine Deviations in Engine Performance Due to Component Replacement

All data on pages 3-47 through 3-54 deleted.

A ONE-PERCENT INCREASE IN ANY ONE OF THE INDEPENDENT VARIABLES CAUSES THE FOLLOWING PERCENTAGE CHANGE IN ANY ONE OF THE DEPENDENT VARIABLES.

-INDEPENDENT VARIABLES-

1- ATMOSPHERIC PRES 0.14696E 02
2- FUEL DENSITY (CONSTANT TEMP). 0.50450E 02
3- FUEL TEMP (CONSTANT DENSITY). 0.60000E 02
4- OXIDIZER DENSITY 0.71380E 02
5- FUEL PUMP INLET PRES 0.45000E 02
6- OXIDE PUMP INLET PRES . . . . .
7- C* CORRECTION. . . . .
8- ACCELERATION . . . .
9- MAIN FUEL ORIFICE RESISTANCE
10- GG OXIDIZER ORIFICE RESISTANC

-DEPENDENT VARIABLES-		1-	2-	3-	4-	5-
ENGINE THRUST	0.15220E 07	-0.1458	-0.9434	0.0191	2.1345	-0.0090
ENGINE SPECIFIC IMPULSE	0.26536E 03	-0.1458	-0.1427	0.0028	0.3103	-0.0014
ENGINE MIXTURE RATIO	0.22701E 01	-0.0000	-1.5589	-0.0067	1.5469	-0.0217
ENGINE FUEL FLOW	0.17537E 04	0.0	0.2815	0.0209	0.7503	0.0074
ENGINE OXIDIZER FLOW	0.39812E 04	-0.0000	-1.2774	0.0142	2.2972	-0.0143
TC INJECTOR END PRESSURE	0.11227E 04	0.0000	-0.7232	0.0171	1.6718	-0.0065
TC C* ACTUAL	0.54464E 04	0.0000	0.1029	0.0007	-0.0879	-0.0015
GIMBAL SUPPLY PRESSURE	0.18260E 04	-0.0000	-0.6190	0.0269	1.6679	0.0017
GG FUEL FLOW	0.12056E 03	0.0000	0.3877	0.0163	0.6319	0.0074
GG OXIDIZER FLOW	0.50199E 02	0.0000	-0.8460	0.0067	1.8511	-0.0086
TURBINE SPEED	0.54884E 04	-0.0000	-0.8006	0.0115	0.8370	-0.0085
TURBINE EXIT STATIC PRES	0.57121E 02	0.0000	-0.6500	0.0213	1.6941	-0.0061
EXHAUST NOZZLE TOTAL PRES	0.48056E 02	-0.0000	-0.5132	0.0197	1.5515	-0.0043
TURBINE MANIFOLD TEMPERATURE	0.15600E 04	0.0000	-2.8169	0.0328	2.9374	-0.0362

Figure 3-39. Engine Influence Coefficients (Predicted) (Engines F-2029 through F-2066)

. 0.65000E 02
. 0.10000E 01
. 0.10000E 01
. 0.34053E 02
. 0.80234E 01

11- TURBINE NOZZLE AREA 0.17000E 02
12- TURBINE EFFICIENCY RATIO 0.10000E 01

-	7-	8-	9-	10-	11-	12-
0544	1.1319	0.0014	-0.0286	-0.2741	0.0972	1.1725
0079	1.1470	0.0002	-0.0059	-0.0395	0.0042	0.1669
0348	-0.0607	0.0007	0.0807	-0.0094	-0.0089	0.0225
0223	0.0270	0.0007	-0.0788	-0.2281	0.0992	0.9900
0571	-0.0338	0.0014	0.0019	-0.2375	0.0902	1.0124
0452	0.9889	0.0011	-0.0305	-0.2387	0.0843	1.0204
0019	1.0165	-0.0000	-0.0068	-0.0031	0.0007	0.0124
0451	0.6101	0.0012	0.0135	-0.3271	0.1132	1.3934
0203	0.3555	0.0007	0.0194	-0.1464	0.3648	0.9301
0450	0.4620	0.0013	-0.0130	-0.3316	0.4805	0.9189
0230	0.2638	0.0007	-0.0077	-0.1780	0.0647	0.7609
0419	0.4510	0.0012	-0.0081	-0.3073	0.4725	0.8174
0389	0.4364	0.0012	-0.0046	-0.2853	0.4641	0.8118
0609	0.3019	0.0016	-0.0724	-0.4540	0.1736	0.1155

3-16. ENGINE STOP CHARACTERISTICS.

3-17. Engine stop characteristics (figures 3-27 through 3-28A) are presented as nominal values. Refer to R-3896-11 for minimum and maximum values.

Valve	Switch Times (Seconds)(a)	Potentiometer Times (Seconds)(a)
Engine Control Valve Closing Signal to:		
Gas generator ball valve starts to close	0.035	--
Gas generator ball valve closing time	0.090	--
Oxidizer valve starts to close	0.120	0.030
Oxidizer valve closing time	0.325	0.540
Fuel valve starts to close	0.115	0.030
Fuel valve closing time	0.930	1.130

(a) Values are based on S-IC stage application.

Figure 3-27. Nominal Cutoff Times From Engine Control Valve Stop Signal

Parameter	Seconds
Engine Control Valve Closing Signal to:	
Thrust chamber pressure leaves 100%	0.074
Thrust chamber pressure decays to 90%	0.118
Thrust chamber pressure decays to 10%	0.573
Thrust chamber pressure decays to zero	1.864

Figure 3-28. Nominal Thrust Decay Time From Engine Control Valve Closing Signal

Parameter	Value
Maximum thrust decrease for 0.075-second interval	448,000 lb
Cutoff impulse	464,000 lb/sec

Figure 3-28A. Nominal Thrust Decay and Cutoff Impulse

3-20. METHODS FOR PREDICTING ENGINE VARIABLE CHARACTERISTICS.

3-21. Methods for predicting engine variable characteristics include engine start time predictions, fuel pump impeller backcasing pressure re-orificing techniques, and methods of determining heat exchanger oxidizer and helium bypass orifice sizes.

3-22. ENGINE START TIME PREDICTIONS (REFERENCED TO ENGINE CONTROL VALVE OPENING SIGNAL AND BASED ON STAGE APPLICATION).

3-23. Three methods are presented to predict engine start time for any engine installed in the stage.

METHOD 1. This method may be used to predict the engine start time from engine control valve start signal to hypergol switch dropout if the engine has been operated under the following acceptance-test conditions and will be operated under the following conditions:

	Oxidizer Pump Inlet Pressure	Fuel Pump Inlet Pressure
Acceptance-Test Conditions	112 ±10 psig	70 ±10 psig
Stage Condition	80 psia	45 psia

$$t_P = \left[-7.087 \times 10^{-2}(t) + 12.146 \times 10^{-5} (P_{IF})(t) - 4.2191 \times 10^{-6} (P_{I_\phi})^2 + 0.14432\right] (112 - P_{I_\phi}) + \left[5.53068 \times 10^{-4} (P_{I_\phi})(t) - 0.114259\right] (70 - P_{IF}) + 2.105\, t - 1.026$$

t_P = Predicted time from engine control valve start signal to hypergol switch dropout for stage test (seconds)

t = Acceptance test time from engine control valve start signal to hypergol switch dropout (seconds)

P_{I_ϕ} = Pre-start oxidizer pump inlet pressure during acceptance test (psig)

P_{IF} = Pre-start fuel pump inlet pressure during acceptance test (psig)

METHOD 2. This method may be used to predict engine start time from engine control valve start signal to hypergol switch dropout if the engine has been operated with any pre-start inlet pressures other than those specified in Method 1, and will be operated under the following stage conditions: (If this calculation is programmed, use "double precision" because of the high exponents involved.)

	Oxidizer Pump Inlet Pressure	Fuel Pump Inlet Pressure
Acceptance-Test Conditions	P_{I_ϕ}	P_{IF}
Stage Conditions	80 psia	45 psia

$$t_P = 3.5041(t) \left[\frac{1}{f(P_{I_\phi},\ P_{IF})}\right]$$

$$f(P_{I_\phi},\ P_{IF}) = K_1 (P_{I_\phi}) + K_2 (P_{IF}) + K_3 + K_4 (P_{I_\phi})^4 + K_5 (P_{I_\phi})^5 + K_6 \left(\frac{P_{IF}}{P_{I_\phi}}\right)^2 + K_7 \frac{(P_{IF})^2}{(P_{I_\phi})^5} + K_8 \frac{(P_{IF} + 250)^2}{(P_{I_\phi})^3}$$

$K_1 = -0.34146221 \times 10^{-1}$

$K_2 = -0.34316603 \times 10^{-2}$

$K_3 = 0.48888479 \times 10$

$K_4 = 0.10864867 \times 10^{-7}$

$K_5 = -0.43755169 \times 10^{-10}$

$K_6 = 0.82104817$

$K_7 = -0.54861973 \times 10^{5}$

$K_8 = 0.26750823 \times 10$

t_P = Predicted time from engine control valve start signal to hypergol switch dropout for stage test (seconds)

t = Acceptance test time from engine control valve start signal to hypergol switch dropout (seconds) at inlet conditions of P_{I_ϕ} and P_{IF} (psig)

P_{I_ϕ} = Pre-start oxidizer pump inlet pressure during acceptance test (psig)

P_{IF} = Pre-start fuel pump inlet pressure during acceptance test (psig)

f = Function of

METHOD 3. This method may be used to predict engine start time from engine control valve start signal to hypergol switch dropout if the engine will be operated at stage conditions other than an oxidizer pump inlet pressure of 80 psia and a fuel pump inlet pressure of 45 psia. (If this calculation is programmed, use "double precision" because of the high exponents involved.)

	Oxidizer Pump Inlet Pressure	Fuel Pump Inlet Pressure
Acceptance-Test Conditions	$P_{I\phi}$	P_{IF}
Stage Conditions	$\hat{P}_{I\phi}$	$\hat{P}_{IF}$

a. Solve for a standardized time $(\hat{t})$ from engine control valve start signal to hypergol switch dropout using the following equations:

$$\hat{t} = \hat{f}(\hat{P}_{I\phi}, \hat{P}_{IF}) = K_1(\hat{P}_{I\phi}) + K_2(\hat{P}_{IF}) + K_3 + K_4(\hat{P}_{I\phi})^4 + K_5(P_{I\phi})^5 + K_6\left(\frac{\hat{P}_{IF}}{\hat{P}_{I\phi}}\right)^2 + K_7\frac{(\hat{P}_{IF})^2}{(P_{I\phi})^5} + K_8\frac{(\hat{P}_{IF}+250)^2}{(P_{I\phi})^3}$$

$K_1 = -0.34146221 \times 10^{-1}$

$K_2 = -0.34316603 \times 10^{-2}$

$K_3 = 0.48888479 \times 10$

$K_4 = 0.10884867 \times 10^{-7}$

$K_5 = -0.43755169 \times 10^{-10}$

$K_6 = 0.82104817$

$K_7 = -0.54861973 \times 10^{5}$

$K_8 = 0.26750823 \times 10$

$\hat{P}_{I\phi}$ = Desired pre-start oxidizer pump inlet pressure (psig)

$\hat{P}_{IF}$ = Desired pre-start fuel pump inlet pressure (psig)

$\hat{f}$ = Function of

b. Solve for predicted time (t_P) from engine control valve start signal to hypergol switch dropout using the following equation:

$$t_P = \hat{t}\,(t)\left[\frac{1}{f(P_{I\phi}, P_{IF})}\right]$$

$$f(P_{I\phi}, P_{IF}) = K_1(P_{I\phi}) + K_2(P_{IF}) + K_3 + K_4(P_{I\phi})^4 + K_5(P_{I\phi})^5 + K_6\left(\frac{P_{IF}}{P_{I\phi}}\right)^2 + K_7\frac{(P_{IF})^2}{(P_{I\phi})^5} + K_8\frac{(P_{IF}+250)^2}{(P_{I\phi})^3}$$

$K_1 = -0.34146221 \times 10^{-1}$

$K_2 = -0.34316603 \times 10^{-2}$

$K_3 = 0.48888479 \times 10$

$K_4 = 0.10884867 \times 10^{-7}$

$K_5 = -0.43755169 \times 10^{-10}$

$K_6 = 0.82104817$

$K_7 = -0.54861973 \times 10^{5}$

$K_8 = 0.26750823 \times 10$

t_P = Predicted time from engine control valve start signal to hypergol switch dropout for stage test (seconds)

t = Acceptance test time from engine control valve start signal to hypergol switch dropout (seconds) at inlet conditions of $P_{I\phi}$ and P_{IF} (psig)

$\hat{t}$ = Standardized time from engine control valve start signal to hypergol switch dropout (seconds) calculated in step a

$P_{I\phi}$ = Pre-start oxidizer pump inlet pressure during acceptance test (seconds)

P_{IF} = Pre-start fuel pump inlet pressure during acceptance test (seconds)

f = Function of

3-24. After the predicted time from engine control valve start signal to hypergol switch dropout has been calculated by Method 1, 2, or 3, the predicted stage time from engine control valve start signal to 90 percent (1,370K) of rated thrust may be calculated. In the stage, the predicted time from hypergol switch dropout to 100 psig chamber pressure is 0.425 second.

Predicted time from engine control valve start signal to 90 percent thrust $= t_P + 1.100$ seconds

t_P = Predicted time from engine control valve start signal to hypergol switch dropout.

3-25. FUEL PUMP IMPELLER BACKCASING PRESSURE RE-ORIFICING TECHNIQUE.

3-26. RE-ORIFICING WITH NO CHANGE IN FUEL PUMP OPERATING CONDITIONS. If the fuel pump inlet pressures and speed are not to be changed between the latest test and the next test, use the following equation to re-orifice the balance cavity supply line to target for fuel impeller backcasing pressure of 250 psig:

$$D_2 = \sqrt{0.15634 - \frac{P_1}{1599} + D_1^{\,2}}$$

D_1 = Supply orifice diameter from latest test

P_1 = Fuel impeller backcasing pressure from latest test

D_2 = Supply orifice diameter to be used on next test

3-27. RE-ORIFICING WITH CHANGES IN FUEL PUMP INLET CONDITIONS. If the fuel pump inlet pressure for the next test is to be different from the fuel pump inlet pressure of the latest test, the fuel impeller backcasing pressure measured on the latest test should be projected to that which would have occurred if the test had been run under the new inlet pressure. This corrected pressure may then be used in the re-orificing procedure outlined in paragraph 3-25. Calculate the corrected fuel impeller backcasing pressure using the following equation:

$$P_{BCN} = P_{DFN} - \left[\frac{P_{DFL} - P_{BCL}}{P_{DFL} - P_{IFL}}\right] \left(P_{DFN} - P_{IFN}\right)$$

P_{DFL} = Fuel discharge pressure observed on latest test

P_{IFL} = Fuel inlet pressure observed on latest test

P_{BCL} = Fuel impeller backcasing pressure observed on latest test

P_{DFN} = Fuel discharge pressure expected on next test

P_{IFN} = Fuel inlet pressure expected on next test

P_{BCN} = Fuel impeller backcasing pressure corrected for new inlet conditions

The new orifice diameter may then be calculated using the re-orificing equation (paragraph 3-26), with $P_{BCN} = P_1$.

3-28. RE-ORIFICING WITH CHANGES IN TURBOPUMP SPEED. If a significant change in turbopump speed (more than 40 rpm) is anticipated between the latest test and the next test, the fuel impeller backcasing pressure from the latest test must then be corrected to new turbopump speed before the re-orificing equation (paragraph 3-26) can be used. The present technique uses past component and engine turbopump fuel discharge pressures, fuel impeller backcasing pressures, fuel inlet pressures, and speed data for the specific turbopump being re-orificed. The fuel impeller backcasing pressure for each test should be corrected to the fuel pump inlet pressure expected on the next engine test, using the equation outlined in paragraph 3-27. This corrected fuel impeller backcasing pressure should be plotted against the turbopump speed observed during that test. The resulting curve determines the corrected fuel impeller backcasing pressure at the turbopump speed expected on the next test. The resulting value of fuel impeller backcasing pressure determines the new fuel impeller backcasing orifice diameter from the equation outlined in paragraph 3-26.

3-29. <u>HEAT EXCHANGER PERFORMANCE EVALUATION AND PREDICTION.</u>

3-30. Heat exchanger performance is determined from operational characteristics of the heat exchanger using data obtained during testing of the heat exchanger. The calculations necessary to determine heat exchanger performance are made in a computer program, which requires data input as listed in figure 3-29. All listed input is required except for the LOX coil outlet pressure. Inclusion of the LOX coil outlet pressure will enable the LOX coil resistance to be calculated. Standardized data are included because they are required data; however, they normally are not changed from the nominal values listed in figure 3-29. Operating data should be obtained from a performance data interval of 3.0 to 3.2 seconds duration that starts at or after 20 seconds of engine effective duration. Output from the program summarizes heat exchanger operation at site conditions, determines coil outlet temperatures at standard inlet conditions, predicts coil outlet temperatures at the target time of a subsequent test, and calculates the diameter of the coil bypas orifice required to achieve the target coil outlet temperature at standard inlet conditions and at the target time of a subsequent test.

Type of Data	Parameter		
	Name	Nominal Value	Units
Identification Data	Engine serial number		
	Heat exchanger serial number		
	Test number		
Test Condition Data	Test duration		Seconds
	Ambient pressure		psi
	Time of slice start		Seconds
Operational Data	Turbine exhaust temperature		°F
	Sea-level turbine exhaust temperature		°F
	LOX coil flowrate		lb/sec
	LOX coil inlet temperature		°F
	LOX coil outlet temperature		°F
	LOX coil outlet pressure (optional)		psia
	Helium coil flowrate		lb/sec
	Helium coil inlet temperature		°F
	Helium coil outlet temperature		°F
Standardized Data	Anticipated additional operation time to target time	35	Seconds
	LOX coil flowrate	4	lb/sec
	LOX coil inlet temperature	-288	°F
	LOX coil outlet target temperature	470	°F
	Helium coil flowrate	0.6	lb/sec
	Helium coil inlet temperature	-345	°F
	Helium coil outlet target temperature	255	°F

Figure 3-29. Heat Exchanger Performance Evaluation and Prediction Input Data Requirements

3-31. HEAT EXCHANGER COMPUTER PROGRAM OPTIONS.

3-32. In addition to the performance evaluations and predictions (paragraph 3-30), the heat exchanger computer program contains the following optional capabilities:

a. Enables predictions to be based upon specified bypass ratios rather than bypass orifice diameters.

b. Enables heat exchanger performance to be predicted with specified alternate bypass orifice diameters.

c. Enables flowrates to be computed from flowmeter nozzle data.

d. Enables average performance to be established from a series of tests.

e. Enables coil outlet temperature data to be adjusted for instrumentation system lag when data is obtained during a transient condition.

3-33 through 3-37. (Deleted)

All data on pages 3-29 through 3-38, figures 3-30 through 3-38 deleted.

3-40. CALCULATIONS INVOLVING A TYPICAL ENGINE.

3-41. For calculations involving a typical engine, the initial values would be the same as the nominal values, as follows:

$$F_{E_i} = F_{E_N} \qquad P_{a_i} = P_{a_N} \qquad T_{F_i} = T_{F_N}$$

$$\rho_{F_i} = \rho_{F_N} \qquad \rho_{O_i} = \rho_{O_N}$$

$$P_{F_i} = P_{F_N} \qquad P_{O_i} = P_{O_N}$$

The following are the calculations used to determine the thrust of the engine when operated under the following conditions:

a.	Atmospheric pressure	=	3.90 psia
b.	Fuel temperature	=	75° F
c.	Fuel density	=	50.45 lb/cu ft
d.	Oxidizer density	=	70.90 lb/cu ft
e.	Fuel pump inlet pressure	=	42.00 psia
f.	Oxidizer pump inlet pressure	=	89.55

$$\frac{F_E - 1,522,000}{1,522,000} = \frac{3.90 - 14.696}{14.696}(-0.1458) + \left(\frac{75.00 - 60.00}{60.00}\right)(0.0191) + \left(\frac{50.45 - 50.45}{50.45}\right)(-0.9434) + \left(\frac{70.90 - 71.38}{71.38}\right)(2.1345) + \left(\frac{42.00 - 45.00}{45.00}\right)(-0.0090) + \left(\frac{89.55 - 65.00}{65.00}\right)(0.0544)$$

$$\frac{F_E - 1,522,000}{1,522,000} = (-0.7346)(-0.1458) + (0.2500)(0.0191) + (0.0 \quad)(-0.9434) + (-0.0067)(2,1345) + (-0.0667)(0.0090) + (0.3777)(0.0544)$$

$$= +0.1187 \text{ or } +11.87 \text{ percent change}$$

$$F_E = +0.1187\,(1,522,000) + 1,522,000$$

$$= +180,700 + 1,522,000 = 1,702,700$$

The incremental thrust has been found to be 180,700 lb for the conditions stated, yielding a final engine thrust of 1,702,700 lb. Propellant densities may be estimated from measured temperature and pressure data with the aid of figures 3-40 and 3-41. Figure 3-40 presents the relationship between the temperature and density for a nominal cut of RP-1 fuel. When the density of a batch of RP-1 is known at one temperature, the density at another temperature can be determined with the slope of the nominal RP-1 line shown in figure 3-40. The effect of pressure on the density of RP-1 is small and may be ignored for inlet conditions encountered on the engine. Figure 3-41 presents the relationship between liquid oxygen temperature, pressure, and density. Two density-versus-temperature curves are presented to show the effect of varying inlet pressure on oxygen density.

3-42. CALCULATIONS INVOLVING A SPECIFIC ENGINE.

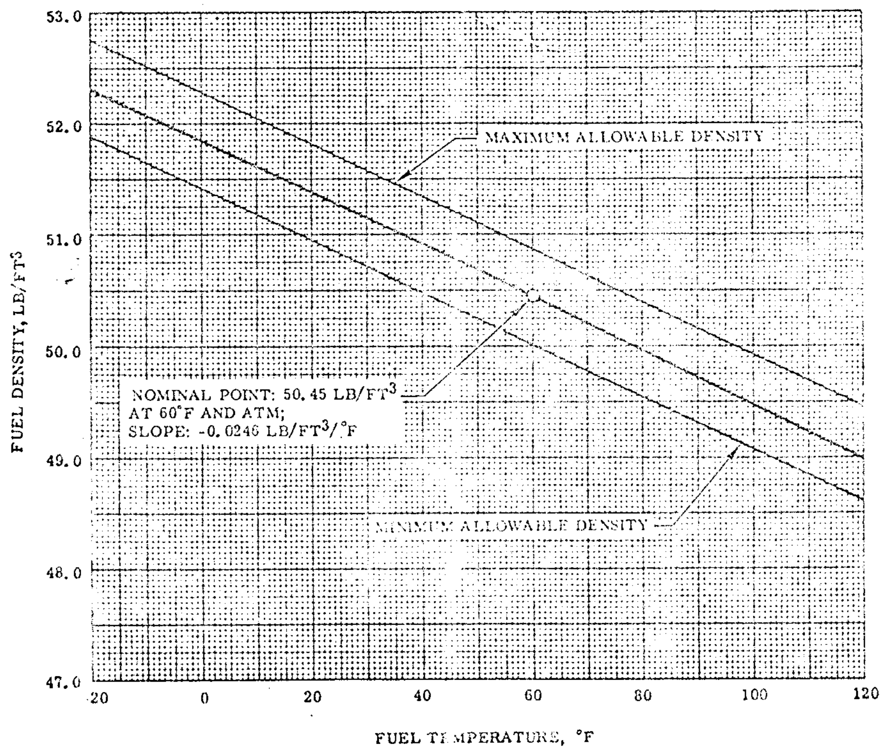
3-43. When the values of actual engine parameters differ from those used as nominal values in the table of influence coefficients, the "delta method" of application of influence coefficients is used. This procedure consists of computing an incremental change of variables rather than a percentage change of these variables. The incremental change is then applied to the actual engine value. This effect can be accomplished by using the equation of the quantities

$$F_{E_i},\ P_{a_i},\ F_i,\ \rho_{O_i},\ P_{F_i},\ \text{and } P_{O_i},$$

which are defined as the actual engine values of these parameters. All other quantities are as defined previously.

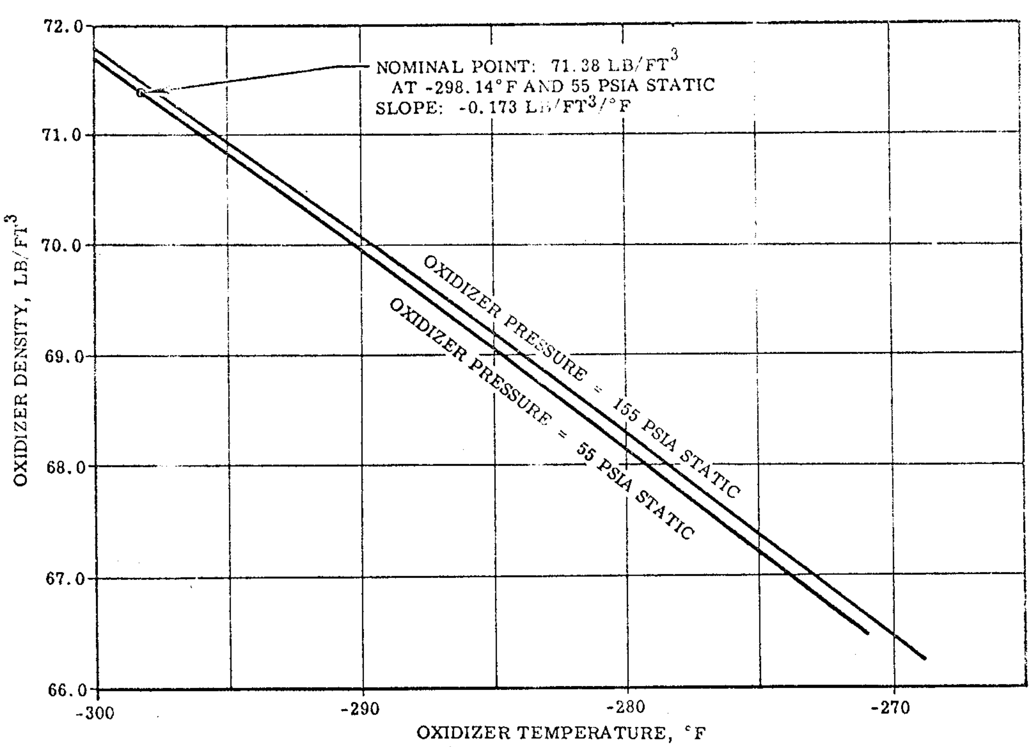
3-43A. TEST TREND CORRECTIONS.

3-43B. During a test, the engine exhibits characteristic trends that may be predicted with the use of influence coefficients. Nominal and actual performance values are established during a time interval of 35-38 seconds of burn time. Changes occur in turbine operational characteristics resulting from coke deposits on internal turbine surfaces and thermal expansion in the turbine assembly. Performance changes are calculated for burn time using figures 3-41A and 3-41B. Figure 3-41A presents the percentage change in turbine nozzle area as a



F1-1-114

Figure 3-40. RP-1 Fuel Density Versus Temperature



F1-1-115

Figure 3-41. Oxidizer Density Versus Temperature

R-3896-1

TECHNICAL MANUAL

ENGINE DATA

F-1 ROCKET ENGINE

(ROCKETDYNE)

(NASA-CR-143972) F-1 ROCKET ENGINE DATA MANUAL (Rocketdyne) 233 p

N75-76409

Unclas
00/98 42669

CHANGE NOTICE

LATEST CHANGED PAGES ... THE SAME PAGES OF ...

insert changed pages ... publication. Destroy superseded pages.

PUBLISHED UNDER AUTHORITY OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MARCH 1967
CHANGE No. 12 — 12 MAY 1972

3-45. ENGINE TEST INSTRUMENTATION.

3-46. A list of the available engine instrumentation taps is presented in figure 3-46. Selection of instrumentation to determine engine operation and performance during static tests shall be a customer requirement. Recommended instrument range and instrument precision is also shown in figure 3-46. Refer to section II for instrumentation tap locations.

Parameter (Pressure)	Range (psig)	Precision (Percent)	Tap	Recording (Low)	Frequency (High)
LOX Pump Inlet(a)(b)	0-200		[illegible]		X
LOX Pump Inlet(c)	0-200	±0.50	[illegible]	X	
No. 1 LOX Pump Discharge	0-2,000	±0.50	[illegible]-1	X	
No. 2 LOX Pump Discharge	0-2,000	±0.50	[illegible]	X	
No. 1 LOX Pump Discharge(a)(b)	0-2,000		PO2d-1		X
No. 2 LOX Pump Discharge(a)(b)	0-2,000		PO2c-2		X
No. 1 Main LOX Valve Inlet	0-2,000	±1.00	PO3-1	X	
No. 2 Main LOX Valve Inlet	0-2,000	±1.00	PO3-2	X	
GG LOX Valve Inlet	0-2,000	±1.00	GO1a	X	
GG LOX Valve Inlet(a)	0-2,500		GO1b	X	
GG LOX Injection(a)	0-1,500	[illegible]	[illegible]	X	
LOX Pump Seal Cavity	0-25	±1.00	PO7b	X	
No. 1 LOX Dome Inlet	0-2,000	±1.00	CO1b-1	X	
No. 2 LOX Dome Inlet	0-2,000	±1.00	CO1b-2	X	
LOX Injection	0-2,000	±1.00	CO3c	X	
LOX Injection(a)(b)	0-2,000		CO3h		X
Heat Exchanger LOX Inlet	0-2,000	±1.00	HO1c	X	
Heat Exchanger GOX Outlet	0-2,000	±1.00	HO4c	X	
No. 1 Fuel Pump Inlet(c)	0-200	±0.50	[illegible]-1	X	
No. 1 Fuel Pump Inlet(a)(b)	0-200		KF7a-1		X
No. 2 Fuel Pump Inlet(c)	0-200	±0.50	KF6d-2	X	
No. 1 Fuel Pump Discharge	0-2,500	±0.50	PF2b-1	X	
No. 1 Fuel Pump Discharge(a)(b)	0-2,500		PF2d-1		X
No. 1 Fuel Pump Discharge	0-2,500		PF2c-1	X	
No. 2 Fuel Pump Discharge	0-2,500	±0.50	PF2b-2	X	
No. 2 Fuel Pump Discharge(a)(b)	0-2,500		PF2c-2		X
No. 1 Main Fuel Valve Inlet	0-2,500	±1.00	PF3a-1	X	
No. 2 Main Fuel Valve Inlet	0-2,500	±1.00	PF3a-2	X	
Fuel Manifold	0-2,000	±1.00	CF1c	X	
Fuel Manifold(a)(b)	0-2,000		CF1b		X
Fuel Injection	0-2,000	±1.00	CF2c	X	
Fuel Injection(a)(b)	0-2,000		CF2a		X
Fuel Impeller Backcasing	0-1,000	±1.00	PF10	X	
GG Fuel Valve Inlet	0-2,000	±1.00	GF1	X	
GG Fuel Injection	0-1,500	±1.00	GF2a	X	
LOX Pump Bearing Jet	0-1,000	±1.00	LB1b	X	
Control System Ground Supply	0-2,500	±1.00	NH0	X	
Control System Supply	0-2,500	±1.00	NH1a	X	
Control System Supply	0-2,500		NH1b	X	

(a) Engine-mounted transducer.
(b) All high-frequency pressure instrumentation must have a range of dc to 10 kc ±2 db.
(c) Mount transducers on facility at pump inlet level within ±1 foot.

Figure 3-46. Engine Instrumentation Parameters (Sheet 1 of 3)

Parameter (Pressure)	Range (psig)	Precision (Percent)	Tag	Recording (Low)	Frequency (High)
Engine Control Closing	0-2,500	±1.00	NH2b	X	
Engine Control Opening	0-2,500	±1.00	NH3b	X	
Common [illegible]draulic Return	0-500	±2.00	NH5b	X	
Common [illegible]draulic Return	0-500		NH5a	X	
Igniter [illegible] Valve Inlet	0-2,500		IF2	X	
Hyper[illegible] Container Inlet	0-2,500		IF3	X	
[illegible] Chamber(a)(b)	0-3,600		CG1a		X
[illegible]	0-1,500	[illegible].50	[illegible]	[illegible]	
[illegible]	0-1,5[illegible]		CG1d	[illegible]	
GG [illegible](a)(b)	0-1,5[illegible]		GG1e		X
GG [illegible]	0-1,500	[illegible]	GG1b	[illegible]	
Turbine [illegible]	0-1,500	[illegible]	GG2a	[illegible]	
Turbine [illegible]	0-100	±0.[illegible]	TG3a	[illegible]	
LOX [illegible]	0-200	[illegible]	[illegible]	[illegible]	
GG [illegible]urge [illegible]	0-500	±[illegible]	CCP	[illegible]	
LOX [illegible]	0-1,500	±[illegible]	CCP	[illegible]	
Heat [illegible]	0-500	[illegible].00	[illegible]	[illegible]	
Heat [illegible]	0-500	[illegible]	[illegible]	[illegible]	
Parameter (Temperature)	**Range (°F)**				
Heat [illegible] GOX Outlet	0-1,000	[illegible].00	HO3	X	
Heat [illegible]er Helium [illegible]	0-500	±1.00	HH4	X	
Turbine [illegible](e)	0-2,000	[illegible].00	GG2b	[illegible]	
Turbine [illegible] (Manifold)(e)	0-2,000	±1.00	[illegible]	[illegible]	
Turbine [illegible](e)	0-2,000	±1.00	TG3b	[illegible]	
Heat [illegible]ger [illegible] Inlet(f)	-300 to -250	±1.00	HO2	[illegible]	
Parameter (Acceleration)	**Range (g rms)**				
[illegible] Inlet Flange(g)	0-250		PZA1-Y(h)		[illegible]
LOX [illegible] Pos. 10(i)	0-707		CZA10-Y(h)		X
LOX [illegible] Pos. 4(i)	0-707		CZA4-Y(h)		[illegible]
Elbow [illegible] Inlet Flange Fuel Pump No. 1 Side(g)(j)	0-250		PZA2-Y(h)		[illegible]
Elbow [illegible] Inlet Flange Fuel Pump No. 1 Side(g)	0-250		PZA3-Z		X

(a) [illegible]-mounted transducer.
(b) [illegible]-frequency pressure instrumentation must have a range of dc to 10 kc ±[illegible] db.
(d) [illegible] engines not incorporating MD70 or MD83 change.
(e) The thermocouple R462 [illegible] gage must be immersed to one-inch depth, which is defined as the [illegible] distance from inside wall of component at point of thermocouple insertion to thermocouple junction.
(f) Heat exchanger oxidizer inlet temperature bulb must be immersed 0.75 ±0.5 inch. (Refer to footnote e.)
(g) 0-3,500 cps low-pass filter.
(h) Centerline of tapped hole is approximately parallel to y-axis.
(i) 0-10,000 cps low-pass filter.
(j) Tri-axial mounting pad.

Figure 3-46. Engine Instrumentation Parameters (Sheet 2 of 3)

Parameter (Acceleration)	Range (g rms)	Precision (Percent)	Tap	Recording Frequency (Low)	(High)
Boss of Fuel Pump Housing(g)(l)	0-250		PZA8-Z(h)		X
Boss of Fuel Pump Housing(g)	0-250		PZA9-Z(k)		X
LOX Dome Pos. 7(j)	0-250		CZA7-X(k)		X
Gas Generator Combustor(g)(l)	0-500		Y-Axis Adapter Block(h)		X
Gas Generator Combustor(g)(l)	0-500		Z-Axis Adapter Block(m)		X
LOX Dome Pos. 1(i)	0-707		CZA1-Y(h)		
LOX Dome Pos. 2(i)	0-250		CZA2-Y(h)		X

(g) 0-3,500 cps low-pass filter.
(h) Centerline of tapped hole is approximately parallel to y-axis.
(i) 0-10,000 cps low-pass filter.
(j) Tri-axial mounting pad.
(k) Centerline of tapped hole is approximately parallel to x-axis.
(l) Adapter 89-[illegible] and bolt 88-702885-3, or equivalent, must [illegible] in [illegible] the gas generator acceleration instrumentation.
(m) Centerline of tapped hole is approximately parallel to z-axis.

Figure 3-46. Engine Instrumentation Parameters (Sheet 8 of 8)

MANUAL DATA SUPPLEMENTS

Manual Data Supplements are issued from time to time to communicate important and urgent information concerning the equipment covered in this manual. These Supplements bear an identifying number and should be filed in this Appendix.

Manual Data Supplements directly affect the data in this manual and will be incorporated into this manual during a future updating effort.

A Supplement Record is issued periodically to indicate the status of Supplements issued for this manual. The status of each Supplement is indicated in the "Supplement Status" column. For active Supplements, no status is entered. For incorporated Supplements, "Incorporated" is entered.

Upon receipt of a Manual Data Supplement, make an appropriate reference to the Supplement in the margin next to the data supplemented. Supplements that have been incorporated into this manual shall be discarded.

MANUAL DATA SUPPLEMENTS

Manual Data Supplements are issued from time to time to communicate important and urgent information concerning the equipment covered in this manual. These Supplements bear an identifying number and should be filed in this Appendix.

Manual Data Supplements directly affect the data in this manual and will be incorporated into this manual during a future updating effort.

A Supplement Record is issued periodically to indicate the status of Supplements issued for this manual. The status of each Supplement is indicated in the "Supplement Status" column. For active Supplements, no status is entered. For incorporated Supplements, "Incorporated" is entered.

Upon receipt of a Manual Data Supplement, make an appropriate reference to the Supplement in the margin next to the data supplemented. Supplements that have been incorporated into this manual shall be discarded.

MANUAL DATA SUPPLEMENT RECORD

This Supplement Record indicates the status of Supplements issued for Technical Manual R-3896-1 as of the date specified above. Supplements which have been incorporated into the manual shall be removed from the Appendix and destroyed. This Supplement Record supersedes Supplement Record dated 14 June 1966.

Supplement Number	Dated	Description	Supplement Status
R-3896-1-1	14 June 1966	Changes methods of determining heat exchanger oxidizer and helium bypass orifice sizes.	Incorporated
R-3896-1-2	30 June 1966	Corrects stage condition fuel and oxidizer inlet pressure requirements for predicting engine start times, and corrects equation used to predict time from engine control valve start signal to hypergol switch dropout.	Incorporated
R-3896-1-3	9 June 1971	Changes the description of the engine envelope dimensions and the engine dry weight to be compatible with data presented in section II.	Incorporated

3-40. CALCULATIONS INVOLVING A TYPICAL ENGINE.

3-41. For calculations involving a typical engine, the initial values would be the same as the nominal values, as follows:

$$F_{E_i} = F_{E_N} \qquad P_{a_i} = P_{a_N} \qquad T_{F_i} = T_{F_N}$$

$$\rho_{F_i} = \rho_{F_N} \qquad \rho_{O_i} = \rho_{O_N}$$

$$P_{F_i} = P_{F_N} \qquad P_{O_i} = P_{O_N}$$

The following are the calculations used to determine the thrust of the engine when operated under the following conditions:

a.	Atmospheric pressure	=	3.90 psia
b.	Fuel temperature	=	75° F
c.	Fuel density	=	50.45 lb/cu ft
d.	Oxidizer density	=	70.90 lb/cu ft
e.	Fuel pump inlet pressure	=	42.00 psia
f.	Oxidizer pump inlet pressure	=	89.55

$$\frac{F_E - 1,522,000}{1,522,000} = \frac{3.90 - 14.696}{14.696}(-0.1458) + \left(\frac{75.00 - 60.00}{60.00}\right)(0.0191) + \left(\frac{50.45 - 50.45}{50.45}\right)(-0.9434) + \left(\frac{70.90 - 71.38}{71.38}\right)(2.1345) + \left(\frac{42.00 - 45.00}{45.00}\right)(-0.0090) + \left(\frac{89.55 - 65.00}{65.00}\right)(0.0544)$$

$$\frac{F_E - 1,522,000}{1,522,000} = (-0.7346)(-0.1458) + (0.2500)(0.0191) + (0.0\ )(-0.9434) + (-0.0067)(2,1345) + (-0.0667)(0.0090) + (0.3777)(0.0544)$$

$$= +0.1187 \text{ or } +11.87 \text{ percent change}$$

$$F_E = +0.1187\,(1,522,000) + 1,522,000$$

$$= +180,700 + 1,522,000 = 1,702,700$$

The incremental thrust has been found to be 180,700 lb for the conditions stated, yielding a final engine thrust of 1,702,700 lb. Propellant densities may be estimated from measured temperature and pressure data with the aid of figures 3-40 and 3-41. Figure 3-40 presents the relationship between the temperature and density for a nominal cut of RP-1 fuel. When the density of a batch of RP-1 is known at one temperature, the density at another temperature can be determined with the slope of the nominal RP-1 line shown in figure 3-40. The effect of pressure on the density of RP-1 is small and may be ignored for inlet conditions encountered on the engine. Figure 3-41 presents the relationship between liquid oxygen temperature, pressure, and density. Two density-versus-temperature curves are presented to show the effect of varying inlet pressure on oxygen density.

3-42. CALCULATIONS INVOLVING A SPECIFIC ENGINE.

3-43. When the values of actual engine parameters differ from those used as nominal values in the table of influence coefficients, the "delta method" of application of influence coefficients is used. This procedure consists of computing an incremental change of variables rather than a percentage change of these variables. The incremental change is then applied to the actual engine value. This effect can be accomplished by using the equation of the quantities

$$F_{E_i},\ P_{a_i},\ F_i,\ \rho_{O_i},\ P_{F_i},\ \text{and}\ P_{O_i},$$

which are defined as the actual engine values of these parameters. All other quantities are as defined previously.

3-43A. TEST TREND CORRECTIONS.

3-43B. During a test, the engine exhibits characteristic trends that may be predicted with the use of influence coefficients. Nominal and actual performance values are established during a time interval of 35-38 seconds of burn time. Changes occur in turbine operational characteristics resulting from coke deposits on internal turbine assembly. Performance changes are calculated for burn time using figures 3-41A and 3-41B for engines F-2029 through F-2065 and figures 3-44 and 3-44A for engines F-2066 and subsequent. Figures 3-41A and 3-44 present the percentage change in turbine nozzle area as a

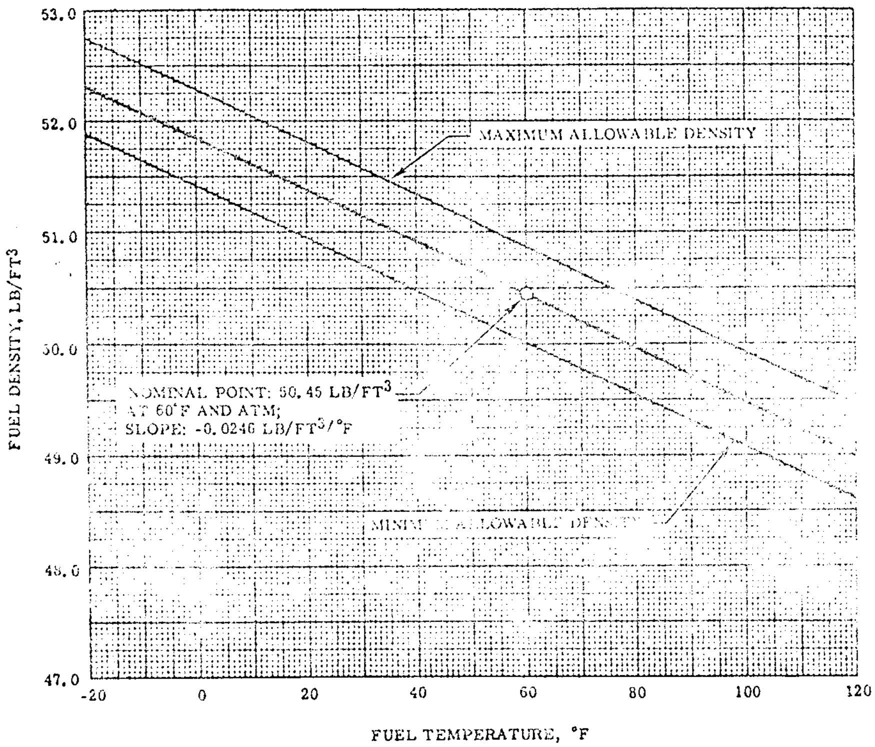


Figure 3-40. RP-1 Fuel Density Versus Temperature

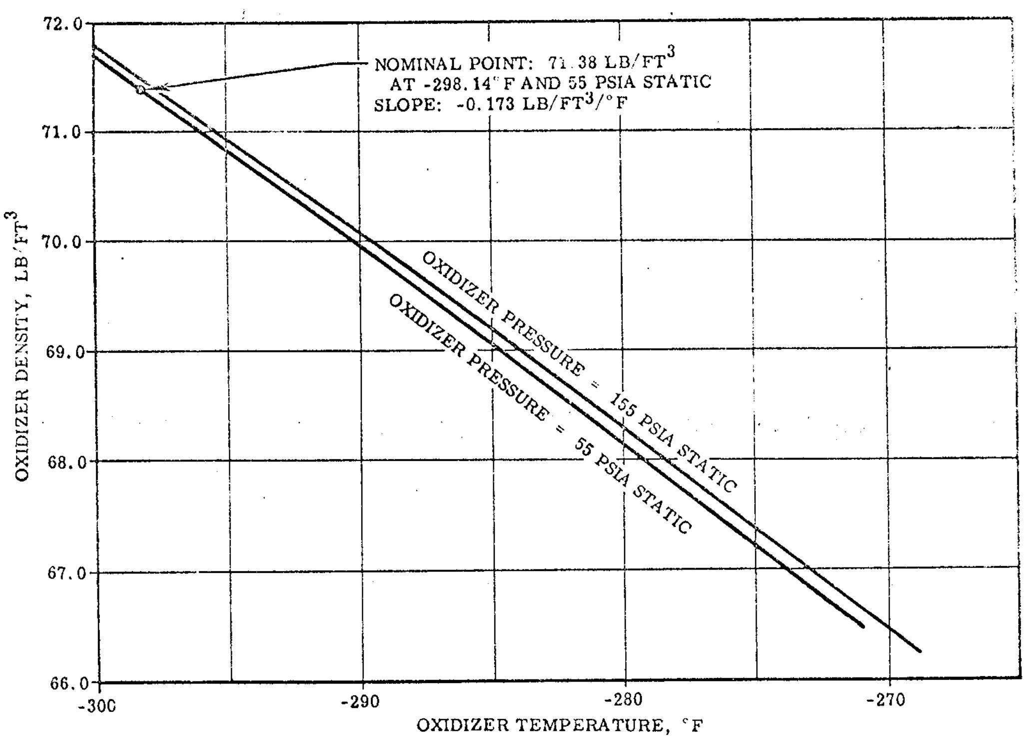


Figure 3-41. Oxidizer Density Versus Temperature

function of burn time, and figures 3-41B and 3-44A present the percentage change in turbine efficiency ratio as a function of burn time. Performance parameters for burn time are adjusted by obtaining the percentage changes expected at the burn time of interest. These percentage changes and the parameter influence coefficients are then multiplied to determine the net percentage change in the performance parameter of interest. In the following example, the thrust of the engine operated under the conditions specified in paragraph 3-41A is adjusted to a 90-second burn time. In figure 3-41A the percentage change in turbine nozzle area at 90 seconds is -3.0 percent. In figure 3-41B the percentage change in turbine efficiency ratio at 90 seconds is -0.25 percent. Therefore, using influence coefficients (figure 3-39),

$$\frac{F_E - 1{,}702{,}700}{1{,}522{,}000} = (-0.0300)\ (0.0972) + (-0.0025)\ (1.1725)$$

$$= -0.00585$$

$$F_E = (-0.00585)\ (1{,}522{,}000) + 1{,}702{,}700$$

$$= -8{,}904 + 1{,}702{,}700$$

$$= 1{,}693{,}796 \text{ lb}$$

Figures 3-41C and 3-44B present thrust differential (based on a predicted performance value from a data slice between 35 and 38 seconds flight time at sea-level and turbopump inlet standard conditions) versus burn time when the performance values are adjusted using influence coefficients from column 11 and 12 of figures 3-39 or 3-43 and turbine nozzle area and turbine efficiency ratio changes from figures 3-41A and 3-41B or 3-44 and 3-44A.

3-44. NONLINEAR CORRECTIONS

3-45. A special computational procedure has been devised to extend the usefulness of engine influence coefficient. This technique is used to allow nonlinear corrections to be made for parameters where the linear approximation is not sufficiently accurate. An example of this method is the C* (characteristic velocity) correction. In this case, a plot of C* correction versus the change in engine mixture ratio is included in addition to the table of influence coefficients. A plot of these parameters for the engine is shown in figures 3-42 and 3-44C. The change in engine mixture ratio is computed for the changes in atmospheric pressure, propellant densities, etc, and with the assumption that the C* correction is zero. With this change in engine mixture ratio, the C* correction is read from the curve. This value of C* correction is used with the other independent variables to recompute the engine mixture ratio, which yields a new value of C* correction. The mixture ratio is then recomputed using the last value of C* correction. This iterative process is continued until the computed mixture ratio ceases to change between two iterations. The corresponding value of C* correction is then used with the other independent variables to compute the changes in the remaining dependent variables. For example, if the final iteration change in engine mixture ratio accompanying the 11.87-percent thrust change in the preceding example were -5 percent, then the C* correction from figure 3-42 is 0.10 percent. Therefore, the true change in engine thrust is $F_E = 11.87 + 1.1319\ (-0.10) = +11.76$ percent.

3-46. COMPONENT REPLACEMENT EFFECTS ON ENGINE PERFORMANCE AT SEA LEVEL.

3-47. Component replacement effects on engine performance at sea level are in R-3896-11. The deviations presented are the maximum expected effects on sea-level engine thrust, mixture ratio, and specific impulse when the listed components are replaced, and are applicable to engines as noted. The following procedure is to be used for determining the maximum expected performance deviations for individual engines.

a. The deviations listed in R-3896-11, corresponding to hardware replaced on the engine, are to be tabulated and included with the Engine Log Book. This tabulation is necessary for future reference and continuous updating when additional replacements are made.

b. The combination of deviations due to the replacement of each individual component determines the expected maximum performance deviation. The combination is accomplished by calculating the square root of the sum of the squares of the deviations listed in R-3896-11, corresponding to each component replaced. Components replaced a second time are treated as a single replacement of the item. (No additional variation is added besides the variation for the component being replaced a second time.) An example is shown in figure 3-45.

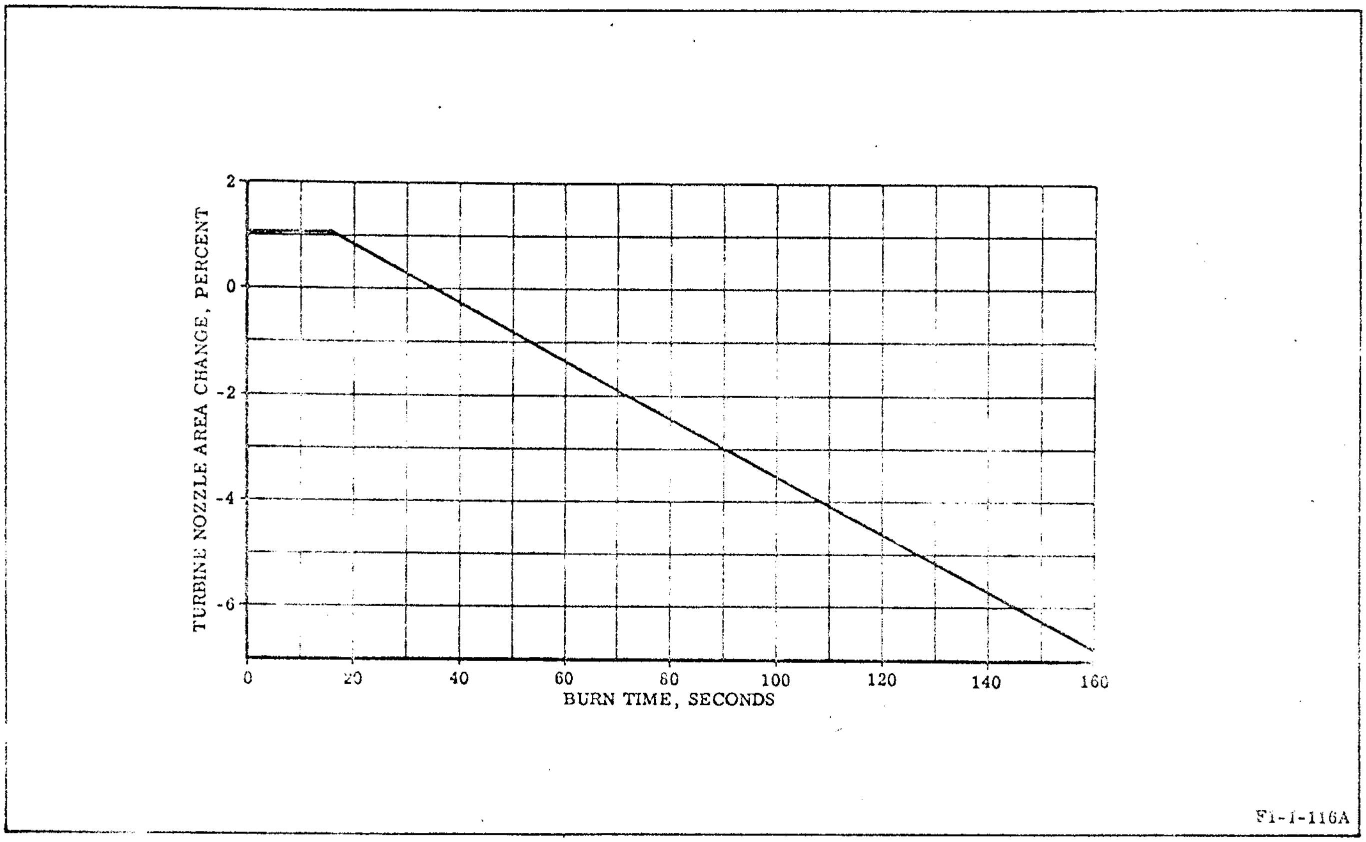


Figure 3-41A. Turbine Nozzle Area Change Versus Burn Time (Engines F-2029 Through F-2065)

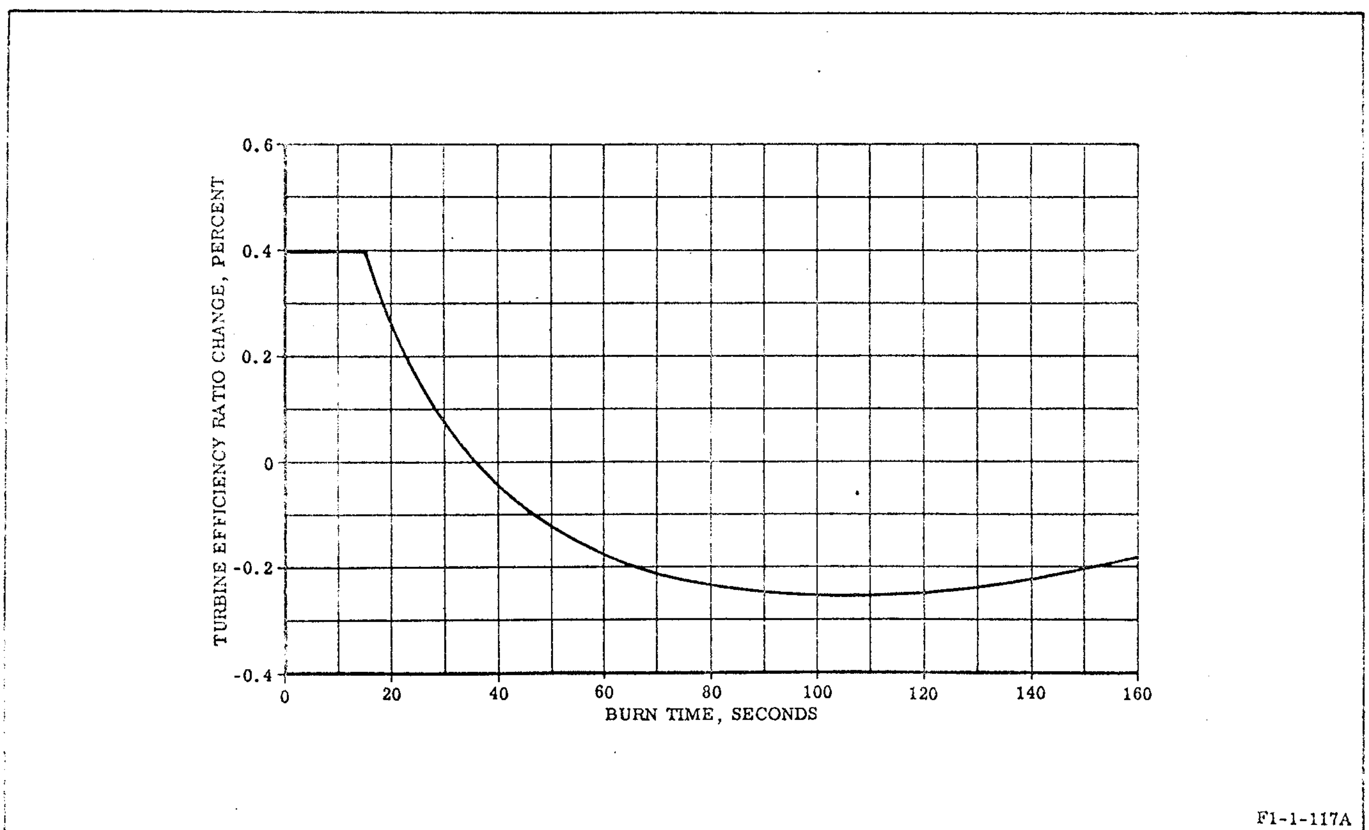


Figure 3-41B. Turbine Efficiency Ratio Curve Change Versus Burn Time (Engines F-2029 Through F-2065) function of burn time, and figure 3-41B presents the percentage change in turbine efficiency ratio as a function of burn time. Performance parameters for burn time are adjusted by obtaining from figures 3-41A and 3-41B the percentage changes expected at the burn time of interest. These percentage changes and the parameter influence coefficients are then multiplied to determine the net percentage change in the performance parameter of interest. In the following example, the thrust of the engine operated under the conditions specified in paragraph 3-41A is adjusted to a 90-second burn time. In figure 3-41A the percentage change in turbine nozzle area at 90 seconds is -3.0 percent. In figure 3-41B the percentage change in turbine efficiency ratio at 90 seconds is -0.25 percent. Therefore, using influence coefficients (figure 3-39),

$$\frac{F_E - 1{,}702{,}700}{1{,}522{,}000} = \begin{array}{l}(-0.0300)\ (0.0972) + \\ (-0.0025)\ (1.1725)\end{array}$$

$$= -0.00585$$

$$F_E = (-0.00585)\ (1{,}522{,}000) + 1{,}702{,}700$$

$$= -8{,}904 + 1{,}702{,}700$$

$$= 1{,}693{,}796 \text{ lb}$$

Figure 3-41C presents thrust differential (based on a predicted performance value from a data slice between 35 and 38 seconds flight time at sea-level and turbopump inlet standard conditions) versus burn time when the performance values are adjusted using influence coefficients from column 11 and 12 of figure 3-39 and turbine nozzle area and turbine efficiency ratio changes from figures 3-41A and 3-41B.

3-44. NONLINEAR CORRECTIONS.

3-45. A special computational procedure has been devised to extend the usefulness of engine influence coefficient. This technique is used to allow nonlinear corrections to be made for parameters where the linear approximation is not sufficiently accurate. An example of this method is the C* (characteristic velocity) correction. In this case, a plot of C* correction versus the change in engine mixture ratio is included in addition to the table of influence coefficients. A plot of these parameters for the engine is shown in figure 3-42. The change in engine mixture ratio is computed for the changes in atmospheric pressure, propellant densities, etc, and with the assumption that the C* correction is zero. With this change in engine mixture ratio, the C* correction is read from the curve. This value of C* correction is used with the other independent variables to recompute the engine mixture ratio, which yields a new value of C* correction. The mixture ratio is then recomputed using the last value of C* correction. This iterative process is continued until the computed mixture ratio ceases to change between two iterations. The corresponding value of C* correction is then used with the other independent variables to compute the changes in the remaining dependent variables. For example, if the final iteration change in engine mixture ratio accompanying the 11.87-percent thrust change in the preceding example were -5 percent, then the C* correction from figure 3-42 is 0.10 percent. Therefore, the true change in engine thrust is $F_E = 11.87 + 1.1319\ (-0.10) = +11.76$ percent.

3-46. COMPONENT REPLACEMENT EFFECTS ON ENGINE PERFORMANCE AT SEA LEVEL.

3-47. Component replacement effects on engine performance at sea level are in R-3896-11. The deviations presented are the maximum expected effects on sea-level engine thrust, mixture ratio, and specific impulse when the listed components are replaced, and are applicable to engines as noted. The following procedure is to be used for determining the maximum expected performance deviations for individual engines.

a. The deviations listed in R-3896-11, corresponding to hardware replaced on the engine, are to be tabulated and included with the Engine Log Book. This tabulation is necessary for future reference and continuous updating when additional replacements are made.

b. The combination of deviations due to the replacement of each individual component determines the expected maximum performance deviation. The combination is accomplished by calculating the square root of the sum of the squares of the deviations listed in R-3896-11, corresponding to each component replaced. Components replaced a second time are treated as a single replacement of the item. (No additional variation is added besides the variation for the component being replaced a second time.) An example is shown in figure 3-45.

A ONE PERCENT INCREASE IN ANY ONE OF THE INDEPENDENT VARIABLES CAUSES THE FOLLOWING PERCENTAGE CHANGE IN ANY ONE OF THE DEPENDENT VARIABLES.

-INDEPENDENT VARIABLES-

1- ATMOSPHERIC PRES.	0.14700E 02	5- FUEL PUMP INLET PRES.	
2- FUEL DENSITY (CONSTANT TEMP) . . .	0.10000E 01	6- OXIDE PUMP INLET PRES	
3- FUEL TEMP (CONSTANT DENSITY) . . .	0.60000E 02	7- C* CORRECTION	
4- OXIDIZER DENSITY	0.10000E 01	8- ACCELERATION	

-DEPENDENT VARIABLES-

		1-	2-	3-	4-	5-
ENGINE THRUST	0.15220E 07	-0.1464	-0.9062	0.0184	2.0994	-0.0083
ENGINE SPECIFIC IMPULSE	0.26534E 03	-0.1464	-0.1391	0.0027	0.3076	-0.0013
ENGINE MIXTURE RATIO	0.22698E 01	-0.0000	-1.5206	-0.0064	1.5094	-0.0201
ENGINE FUEL FLOW	0.17543E 04	0.0	0.2885	0.0201	0.7440	0.0069
ENGINE OXIDIZER FLOW	0.39818E 04	-0.0000	-1.2321	0.0137	2.2534	-0.0131
TC INJECTOR END PRES	0.11248E 04	0.0	-0.6926	0.0164	1.7325	-0.0059
TC C* ACTUAL	0.54514E 04	0.0000	0.0989	0.0007	-0.0840	0.0014
GIMBAL SUPPLY PRESSURE	0.18383E 04	-0.0000	-0.5947	0.0259	1.6450	0.0017
GG FUEL FLOW.	0.11795E 03	-0.0000	0.4077	0.0159	0.6122	0.0073
GG OXIDE FLOW	0.49045E 02	0.0000	-0.8182	0.0060	1.8232	-0.0079
TURBINE SPEED	0.54922E 04	-0.0000	-0.7865	0.0111	0.8233	-0.0080
TURBINE EXIT STATIC PRES	0.58273E 02	0.0000	-0.6503	0.0209	1.6968	-0.0059
EXHAUST NOZZLE TOTAL PRES.	0.46852E 02	0.0	-0.4888	0.0191	1.5281	-0.0039
TURBINE MAINFOLD TEMPERATURE. . . .	0.15560E 04	0.0	-2.8035	0.0323	2.9285	-0.0345

Figure 3-43. Engine Influence Coefficients (Predicted) (Engines F-2066 and Subsequent)

. 0.45000E 02	9- MAIN FUEL ORIFICE RESISTANCE 0.31342E-02
. 0.65000E 02	10- GG OXIDIZER ORIFICE RESISTANCE ... 0.77156E 01
. 0.10000E 01	11- TURBINE INLET NOZZLE AREA 0.17023E 02
. 0.10000E 01	12- TURBINE EFFICIENCY MULTIPLIER ... 0.10000E 01

	7-	8-	9-	10-	11-	12-
45	1.1781	0.0013	-0.0264	-0.2549	0.1254	1.2273
80	1.1544	0.0002	-0.0053	-0.0368	0.0083	0.1749
37	-0.0571	0.0007	0.0690	-0.0085	-0.0076	0.0232
32	0.0633	0.0007	-0.0689	-0.2121	0.1224	1.0362
69	0.0062	0.0013	0.0001	-0.2206	0.1148	1.0595
54	1.0285	0.0011	-0.0278	-0.2219	0.1088	1.0675
18	1.0167	-0.0000	-0.0058	-0.0029	0.0010	0.0130
59	0.6604	0.0012	0.0149	-0.3047	0.1466	1.4607
07	0.3862	0.0007	0.0215	-0.1348	0.3911	0.9808
55	0.5027	0.0013	-0.0124	-0.3093	0.5187	0.9709
34	0.2837	0.0007	-0.0076	-0.1672	0.0841	0.8051
29	0.4931	0.0012	-0.0081	-0.2904	0.5112	0.8618
93	0.4739	0.0012	-0.0037	-0.2657	0.4995	0.8543
12	0.3329	0.0015	-0.0760	-0.4290	0.2032	0.1301

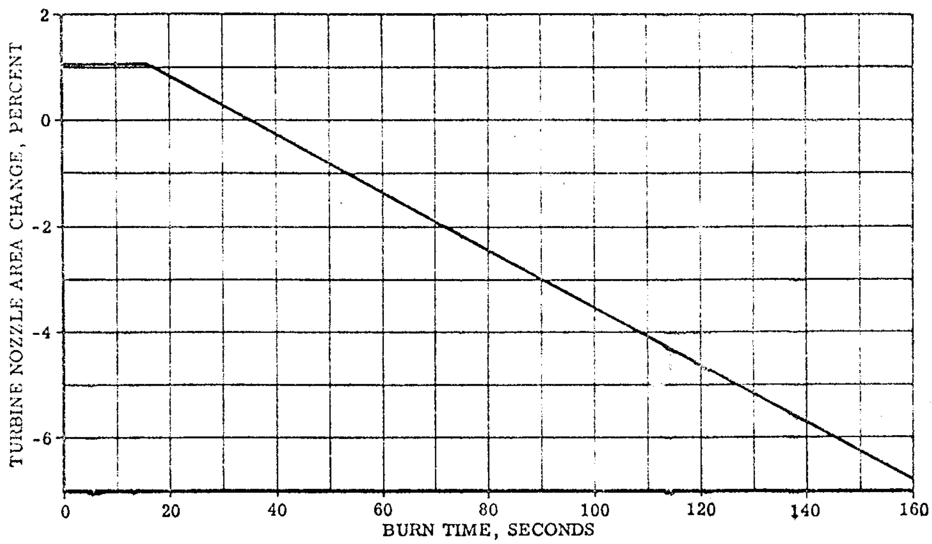


Figure 3-41A. Turbine Nozzle Area Change Versus Burn Time

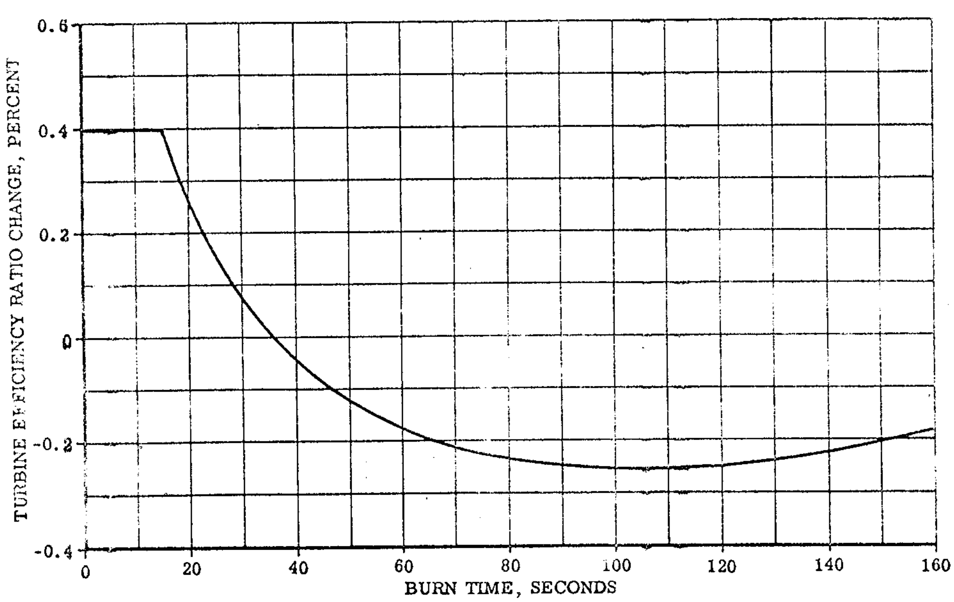


Figure 3-41B. Turbine Efficiency Ratio Curve Change Versus Burn Time

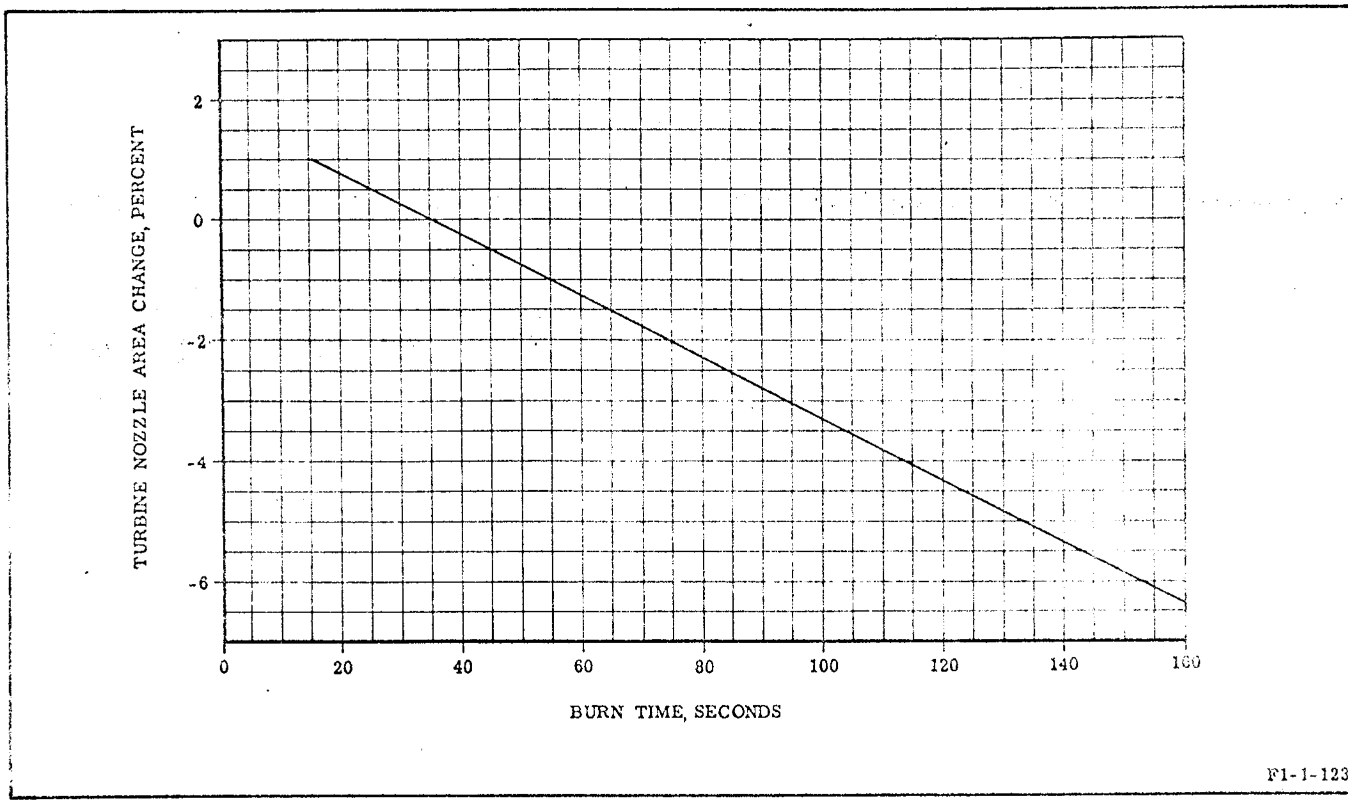


Figure 3-44. Turbine Nozzle Area Change Versus Burn Time (Engines F-2066 and Subsequent)

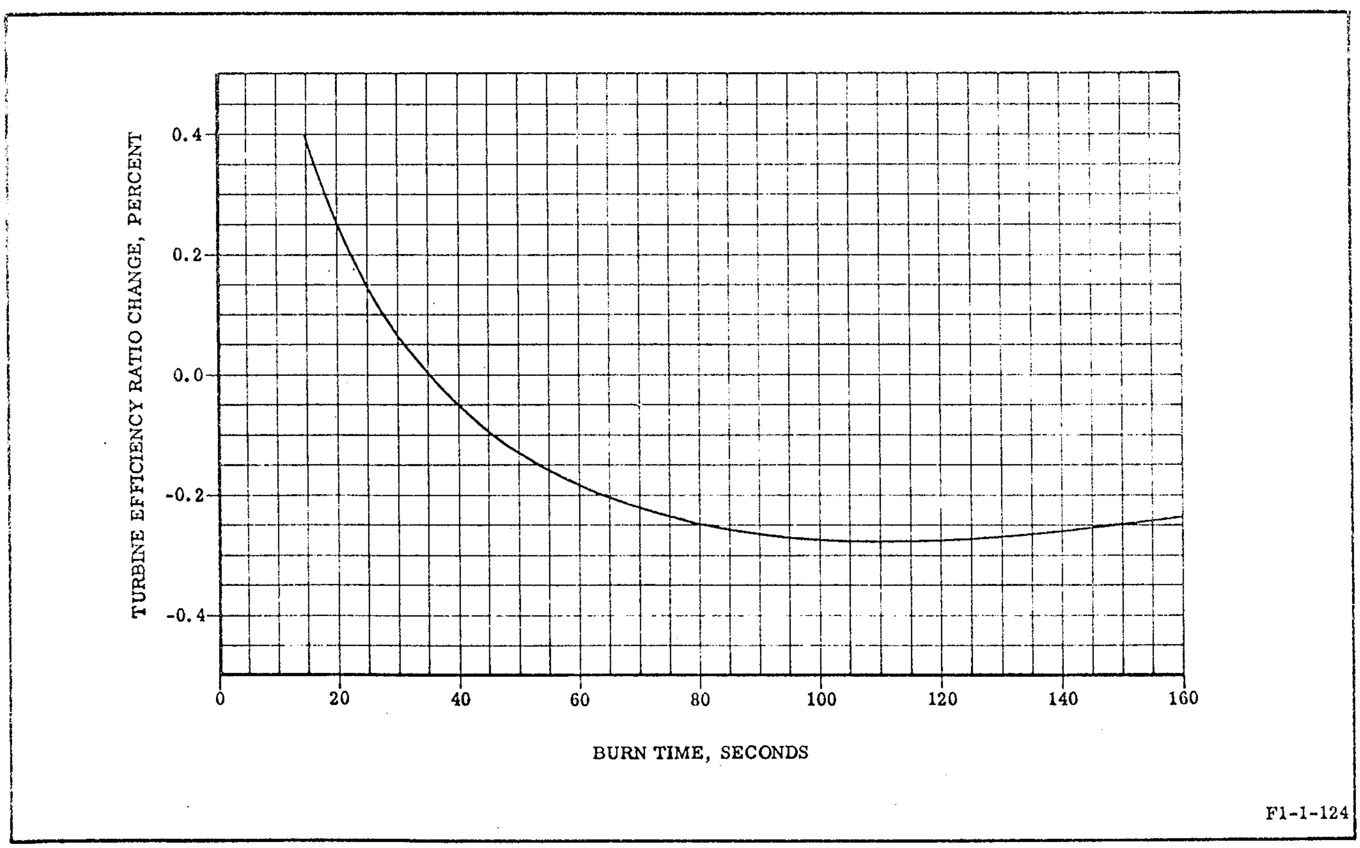


Figure 3-44A. Turbine Efficiency Ratio Curve Change Versus Burn Time (Engines F-2066 and Subsequent)

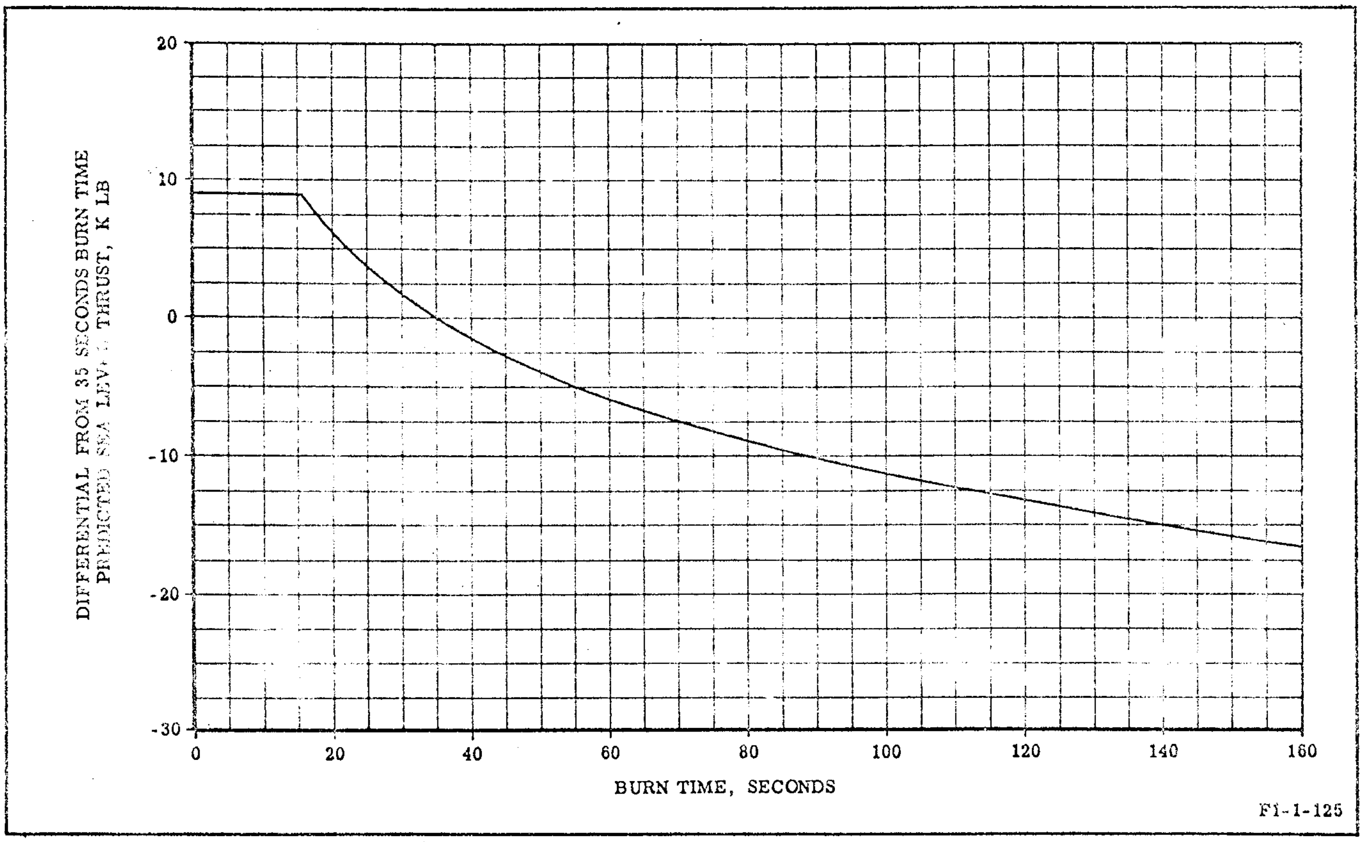


Figure 3-44B. Thrust Trend for Flight Engines (Engines F-2066 and Subsequent)

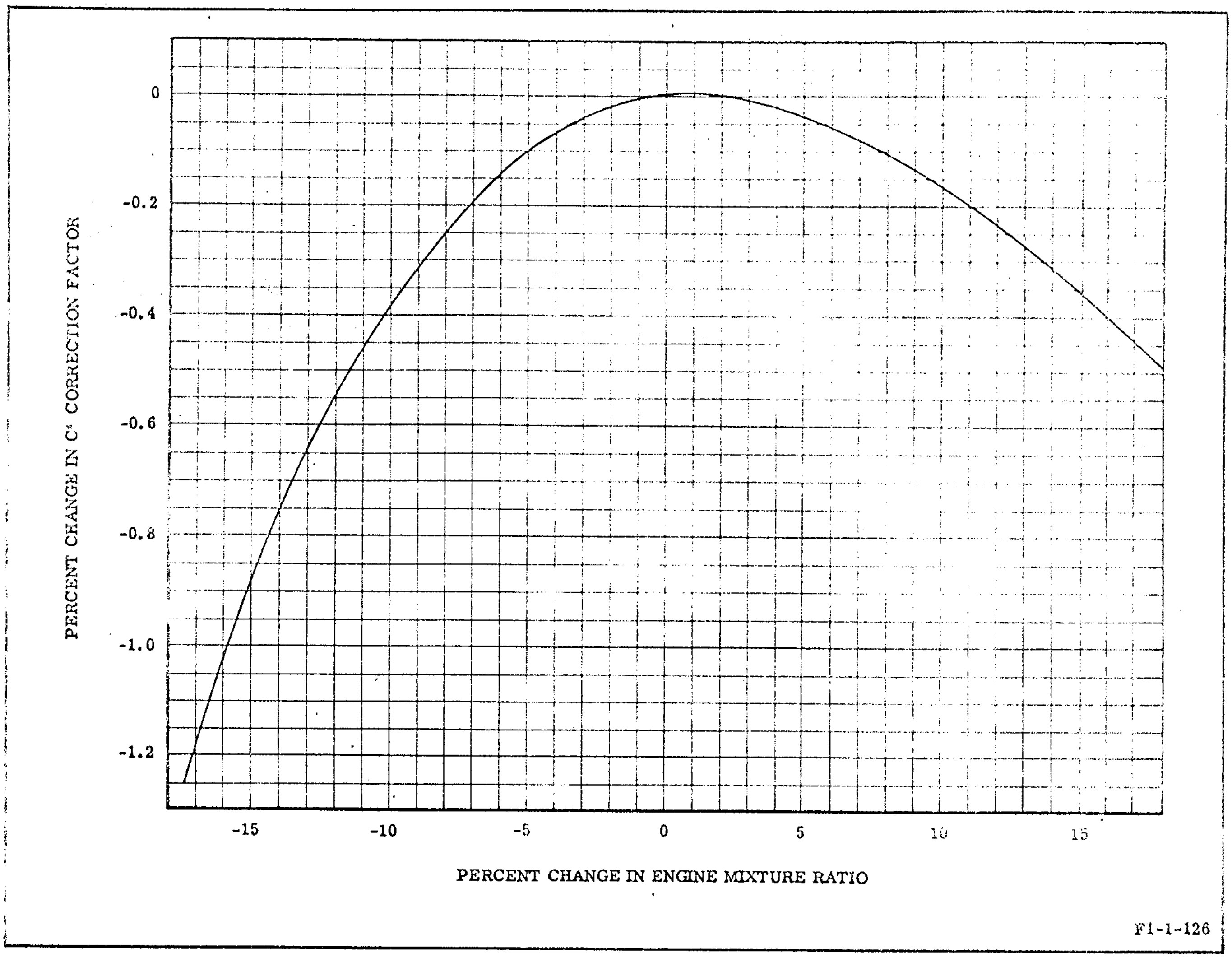


Figure 3-44C. C* Correction Curve (Actual) (Engines F-2066 and Subsequent)

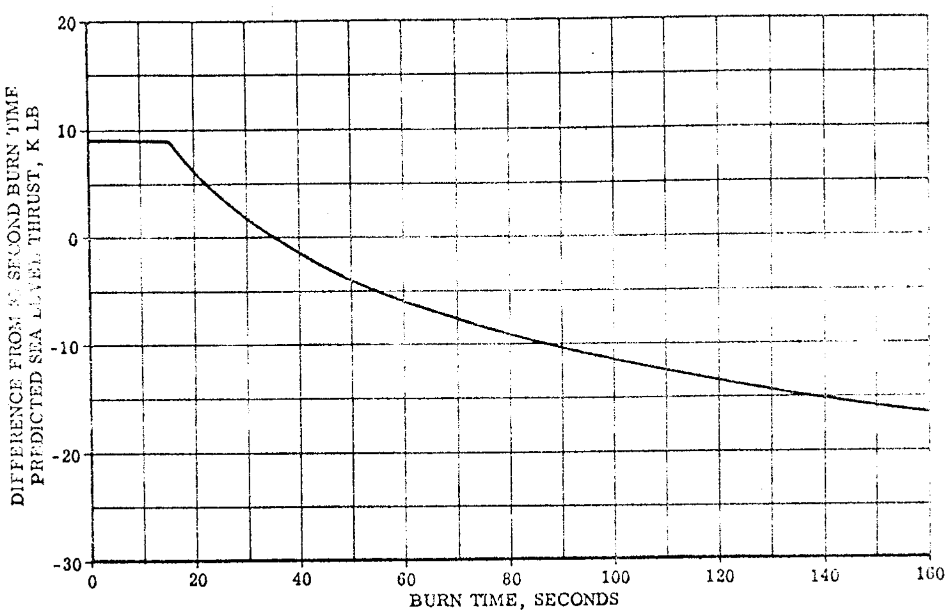
ENGINE XXXX COMPONENT REPLACEMENT LOG

Component Replacement	Thrust Deviation	Mixture Ratio Deviation	Specific Impulse Deviation
No. 1 Fuel Valve	0.9	0.017	0.14
No. 1 Turbopump Fuel Outlet Line	0.3	0.007	0.05
Expected Maximum Deviation as of (Date 1)(d)	$\sqrt{(0.9)^2+(0.3)^2}$ $= 0.9$	$\sqrt{(0.017)^2+(0.007)^2}$ $= 0.018$	$\sqrt{(0.14)^2+(0.05)^2}$ $= 0.15$
No. 1 Turbopump Oxidizer Outlet Line	7.1	0.010	0.14
Expected Maximum Deviation as of (Date 2)(e)	$\sqrt{(0.9)^2+(0.3)^2+(7.1)^2}$ $= 7.2$	$\sqrt{(0.017)^2+(0.007)^2+(0.010)^2}$ $= 0.021$	$\sqrt{(0.14)^2+(0.05)^2+(0.14)^2}$ $= 0.20$
No. 1 Turbopump Fuel Outlet Line	0.3	0.007	0.05
Thrust Chamber Injector	6.5	0.029	0.33
Expected Maximum Deviation as of (Date 3)(f)	$\sqrt{(0.9)^2+(0.3)^2+(7.1)^2+(6.5)^2}$ $= 9.7$	$\sqrt{(0.017)^2+(0.007)^2+(0.010)^2+(0.029)^2}$ $= 0.036$	$\sqrt{(0.14)^2+(0.05)^2+(0.14)^2+(0.33)^2}$ $= 0.39$

(d) First component replacement since delivery (Date 1).
(e) Additional component replaced on (Date 2).
(f) Turbopump fuel outlet line No. 1 replaced second time, also main injector changed on (Date 3).

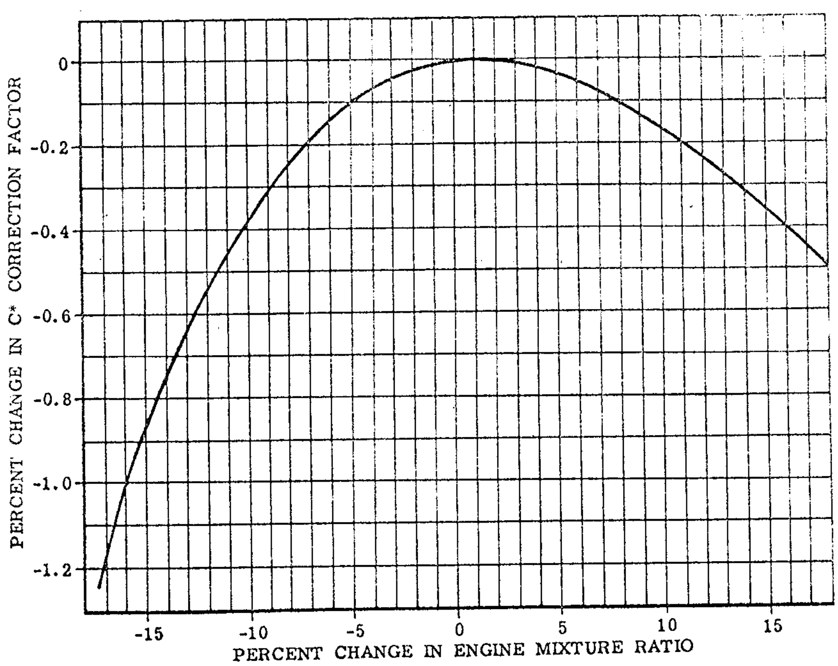
Figure 3-45. Example of Calculations Required to Determine Deviations in Engine Performance Due to Component Replacement

All data on pages 3-47 through 3-54 deleted.



F1-1-121

Figure 3-41C. Thrust Trend for Flight



F1-1-120

Figure 3-42. C* Correction Curve (Actual)

Figures 3-43 and 3-44 deleted.

ENGINE XXXX COMPONENT REPLACEMENT LOG

Component Replacement	Thrust Deviation	Mixture Ratio Deviation	Specific Impulse Deviation
No. 1 Fuel Valve	0.9	0.017	0.14
No. 1 Turbopump Fuel Outlet Line	0.3	0.007	0.05
Expected Maximum Deviation as of (Date 1)(d)	$\sqrt{(0.9)^2+(0.3)^2} = 0.9$	$\sqrt{(0.017)^2+(0.007)^2} = 0.018$	$\sqrt{(0.14)^2+(0.05)^2} = 0.15$
No. 1 Turbopump Oxidizer Outlet Line	7.1	0.010	0.14
Expected Maximum Deviation as of (Date 2)(e)	$\sqrt{(0.9)^2+(0.3)^2+(7.1)^2} = 7.2$	$\sqrt{(0.017)^2+(0.007)^2+(0.010)^2} = 0.021$	$\sqrt{(0.14)^2+(0.05)^2+(0.14)^2} = 0.20$
No. 1 Turbopump Fuel Outlet Line	0.3	0.007	0.05
Thrust Chamber Injector	6.5	0.029	0.33
Expected Maximum Deviation as of (Date 3)(f)	$\sqrt{(0.9)^2+(0.3)^2+(7.1)^2+(6.5)^2} = 9.7$	$\sqrt{(0.017)^2+(0.007)^2+(0.010)^2+(0.029)^2} = 0.036$	$\sqrt{(0.14)^2+(0.05)^2+(0.14)^2+(0.33)^2} = 0.39$

(d) First component replacement since delivery (Date 1).
(e) Additional component replaced on (Date 2).
(f) Turbopump fuel outlet line No. 1 replaced second time, also main injector changed on (Date 3).

Figure 3-45. Example of Calculations Required to Determine Deviations in Engine Performance Due to Component Replacement

All data on pages 3-47 through 3-54 deleted.

A ONE-PERCENT INCREASE IN ANY ONE OF THE INDEPENDENT VARIABLES CAUSES THE FOLLOWING PERCENTAGE CHANGE IN ANY ONE OF THE DEPENDENT VARIABLES.

-INDEPENDENT VARIABLES-

1- ATMOSPHERIC PRES 0.14696E 02
2- FUEL DENSITY (CONSTANT TEMP). 0.50450E 02
3- FUEL TEMP (CONSTANT DENSITY). 0.60000E 02
4- OXIDIZER DENSITY 0.71380E 02
5- FUEL PUMP INLET PRES 0.45000E 02
6- OXIDE PUMP INLET PRES . . . . .
7- C* CORRECTION. . . . .
8- ACCELERATION . . . .
9- MAIN FUEL ORIFICE RESISTANC
10- GG OXIDIZER ORIFICE RESISTAN

-DEPENDENT VARIABLES-		1-	2-	3-	4-	5-
ENGINE THRUST	0.15220E 07	-0.1458	-0.9434	0.0191	2.1345	-0.0090
ENGINE SPECIFIC IMPULSE	0.26536E 03	-0.1458	-0.1427	0.0028	0.3103	-0.0014
ENGINE MIXTURE RATIO	0.22701E 01	-0.0000	-1.5589	-0.0067	1.5469	-0.0217
ENGINE FUEL FLOW	0.17537E 04	0.0	0.2815	0.0209	0.7503	0.0074
ENGINE OXIDIZER FLOW	0.39812E 04	-0.0000	-1.2774	0.0142	2.2972	-0.0143
TC INJECTOR END PRESSURE	0.11227E 04	0.0000	-0.7232	0.0171	1.6718	-0.0065
TC C* ACTUAL	0.54464E 04	0.0000	0.1029	0.0007	-0.0879	-0.0015
GIMBAL SUPPLY PRESSURE	0.18260E 04	-0.0000	-0.6190	0.0269	1.6679	0.0017
GG FUEL FLOW	0.12056E 03	0.0000	0.3877	0.0163	0.6319	0.0074
GG OXIDIZER FLOW	0.50199E 02	0.0000	-0.8460	0.0067	1.8511	-0.0086
TURBINE SPEED	0.54884E 04	-0.0000	-0.8006	0.0115	0.8370	-0.0085
TURBINE EXIT STATIC PRES	0.57121E 02	0.0000	-0.6500	0.0213	1.6941	-0.0061
EXHAUST NOZZLE TOTAL PRES	0.48056E 02	-0.0000	-0.5132	0.0197	1.5515	-0.0043
TURBINE MANIFOLD TEMPERATURE	0.15600E 04	0.0000	-2.8169	0.0328	2.9374	-0.0362

Figure 3-39. Engine Influence Coefficients (Predicted) (Engines F-2029 through F-2066)

. 0.65000E 02
. 0.10000E 01
. 0.10000E 01
. 0.34053E 02
. 0.80234E 01

11- TURBINE NOZZLE AREA 0.17000E 02
12- TURBINE EFFICIENCY RATIO 0.10000E 01

-	7-	8-	9-	10-	11-	12-
0544	1.1319	0.0014	-0.0286	-0.2741	0.0972	1.1725
0079	1.1470	0.0002	-0.0059	-0.0395	0.0042	0.1669
0348	-0.0607	0.0007	0.0807	-0.0094	-0.0089	0.0225
0223	0.0270	0.0007	-0.0788	-0.2281	0.0992	0.9900
0571	-0.0338	0.0014	0.0019	-0.2375	0.0902	1.0124
0452	0.9889	0.0011	-0.0305	-0.2387	0.0843	1.0204
0019	1.0165	-0.0000	-0.0068	-0.0031	0.0007	0.0124
0451	0.6101	0.0012	0.0135	-0.3271	0.1132	1.3934
0203	0.3555	0.0007	0.0194	-0.1464	0.3648	0.9301
0450	0.4620	0.0013	-0.0130	-0.3316	0.4805	0.9189
0230	0.2638	0.0007	-0.0077	-0.1780	0.0647	0.7609
0419	0.4510	0.0012	-0.0081	-0.3073	0.4725	0.8174
0389	0.4364	0.0012	-0.0046	-0.2853	0.4641	0.8118
0609	0.3019	0.0016	-0.0724	-0.4540	0.1736	0.1155

3-16. ENGINE STOP CHARACTERISTICS.

3-17. Engine stop characteristics (figures 3-27 through 3-28A) are presented as nominal values. Refer to R-3896-11 for minimum and maximum values.

Valve	Switch Times (Seconds)[a]	Potentiometer Times (Seconds)[a]
Engine Control Valve Closing Signal to:		
Gas generator ball valve starts to close	0.035	--
Gas generator ball valve closing time	0.090	--
Oxidizer valve starts to close	0.120	0.030
Oxidizer valve closing time	0.325	0.540
Fuel valve starts to close	0.115	0.030
Fuel valve closing time	0.930	1.130

(a) Values are based on S-IC stage application.

Figure 3-27. Nominal Cutoff Times From Engine Control Valve Stop Signal

Parameter	Seconds
Engine Control Valve Closing Signal to:	
Thrust chamber pressure leaves 100%	0.074
Thrust chamber pressure decays to 90%	0.118
Thrust chamber pressure decays to 10%	0.573
Thrust chamber pressure decays to zero	1.864

Figure 3-28. Nominal Thrust Decay Time From Engine Control Valve Closing Signal

Parameter	Value
Maximum thrust decrease for 0.075-second interval	448,000 lb
Cutoff impulse	464,000 lb/sec

Figure 3-28A. Nominal Thrust Decay and Cutoff Impulse

3-20. METHODS FOR PREDICTING ENGINE VARIABLE CHARACTERISTICS.

3-21. Methods for predicting engine variable characteristics include engine start time predictions, fuel pump impeller backcasing pressure re-orificing techniques, and methods of determining heat exchanger oxidizer and helium bypass orifice sizes.

3-22. ENGINE START TIME PREDICTIONS (REFERENCED TO ENGINE CONTROL VALVE OPENING SIGNAL AND BASED ON STAGE APPLICATION).

3-23. Three methods are presented to predict engine start time for any engine installed in the stage.

METHOD 1. This method may be used to predict the engine start time from engine control valve start signal to hypergol switch dropout if the engine has been operated under the following acceptance-test conditions and will be operated under the following conditions:

	Oxidizer Pump Inlet Pressure	Fuel Pump Inlet Pressure
Acceptance-Test Conditions	112 ±10 psig	70 ±10 psig
Stage Condition	80 psia	45 psia

$$t_P = \left[-7.087 \times 10^{-2}(t) + 12.146 \times 10^{-5} (P_{IF})(t) - 4.2191 \times 10^{-6} (P_{I_\phi})^2 + 0.14432\right](112 - P_{I_\phi}) + \left[5.53068 \times 10^{-4} (P_{I_\phi})(t) - 0.114259\right](70 - P_{IF}) + 2.105\, t - 1.026$$

t_P = Predicted time from engine control valve start signal to hypergol switch dropout for stage test (seconds)

t = Acceptance test time from engine control valve start signal to hypergol switch dropout (seconds)

P_{I_ϕ} = Pre-start oxidizer pump inlet pressure during acceptance test (psig)

P_{IF} = Pre-start fuel pump inlet pressure during acceptance test (psig)

METHOD 2. This method may be used to predict engine start time from engine control valve start signal to hypergol switch dropout if the engine has been operated with any pre-start inlet pressures other than those specified in Method 1, and will be operated under the following stage conditions: (If this calculation is programmed, use "double precision" because of the high exponents involved.)

	Oxidizer Pump Inlet Pressure	Fuel Pump Inlet Pressure
Acceptance-Test Conditions	P_{I_ϕ}	P_{IF}
Stage Conditions	80 psia	45 psia

$$t_P = 3.5041(t)\left[\frac{1}{f(P_{I_\phi},\ P_{IF})}\right]$$

$$f(P_{I_\phi},\ P_{IF}) = K_1 (P_{I_\phi}) + K_2 (P_{IF}) + K_3 + K_4 (P_{I_\phi})^4 + K_5 (P_{I_\phi})^5 + K_6\left(\frac{P_{IF}}{P_{I_\phi}}\right)^2 + K_7 \frac{(P_{IF})^2}{(P_{I_\phi})^5} + K_8 \frac{(P_{IF} + 250)^2}{(P_{I_\phi})^3}$$

$K_1 = -0.34146221 \times 10^{-1}$
$K_2 = -0.34316603 \times 10^{-2}$
$K_3 = 0.48888479 \times 10$
$K_4 = 0.10864867 \times 10^{-7}$
$K_5 = -0.43755169 \times 10^{-10}$
$K_6 = 0.82104817$
$K_7 = -0.54861973 \times 10^{5}$
$K_8 = 0.26750823 \times 10$

t_P = Predicted time from engine control valve start signal to hypergol switch dropout for stage test (seconds)

t = Acceptance test time from engine control valve start signal to hypergol switch dropout (seconds) at inlet conditions of P_{I_ϕ} and P_{IF} (psig)

P_{I_ϕ} = Pre-start oxidizer pump inlet pressure during acceptance test (psig)

P_{IF} = Pre-start fuel pump inlet pressure during acceptance test (psig)

f = Function of

METHOD 3. This method may be used to predict engine start time from engine control valve start signal to hypergol switch dropout if the engine will be operated at stage conditions other than an oxidizer pump inlet pressure of 80 psia and a fuel pump inlet pressure of 45 psia. (If this calculation is programmed, use "double precision" because of the high exponents involved.)

	Oxidizer Pump Inlet Pressure	Fuel Pump Inlet Pressure
Acceptance-Test Conditions	$P_{I\phi}$	P_{IF}
Stage Conditions	$\hat{P}_{I\phi}$	$\hat{P}_{IF}$

a. Solve for a standardized time $(\hat{t})$ from engine control valve start signal to hypergol switch dropout using the following equations:

$$\hat{t} = \hat{f}(\hat{P}_{I\phi}, \hat{P}_{IF}) = K_1(\hat{P}_{I\phi}) + K_2(\hat{P}_{IF}) + K_3 + K_4(\hat{P}_{I\phi})^4 + K_5(P_{I\phi})^5 + K_6\left(\frac{P_{IF}}{P_{I\phi}}\right)^2 + K_7\frac{(P_{IF})^2}{(P_{I\phi})^5} + K_8\frac{(\hat{P}_{IF} + 250)^2}{(P_{I\phi})^3}$$

$K_1 = -0.34146221 \times 10^{-1}$
$K_2 = -0.34316603 \times 10^{-2}$
$K_3 = 0.48888479 \times 10$
$K_4 = 0.10864867 \times 10^{-7}$
$K_5 = -0.43755169 \times 10^{-10}$
$K_6 = 0.82104817$
$K_7 = -0.54861973 \times 10^5$
$K_8 = 0.26750823 \times 10$

$\hat{P}_{I\phi}$ = Desired pre-start oxidizer pump inlet pressure (psig)

$\hat{P}_{IF}$ = Desired pre-start fuel pump inlet pressure (psig)

f = Function of

b. Solve for predicted time (t_P) from engine control valve start signal to hypergol switch dropout using the following equation:

$$t_P = \hat{t}\,(t)\left[\frac{1}{f(P_{I\phi}, P_{IF})}\right]$$

$$f(P_{I\phi}, P_{IF}) = K_1(P_{I\phi}) + K_2(P_{IF}) + K_3 + K_4(P_{I\phi})^4 + K_5(P_{I\phi})^5 + K_6\left(\frac{P_{IF}}{P_{I\phi}}\right)^2 + K_7\frac{(P_{IF})^2}{(P_{I\phi})^5} + K_8\frac{(P_{IF} + 250)^2}{(P_{I\phi})^3}$$

$K_1 = -0.34146221 \times 10^{-1}$
$K_2 = -0.34316603 \times 10^{-2}$
$K_3 = 0.48888479 \times 10$
$K_4 = 0.10864867 \times 10^{-7}$
$K_5 = -0.43755169 \times 10^{-10}$
$K_6 = 0.82104817$
$K_7 = -0.54861973 \times 10^5$
$K_8 = 0.26750823 \times 10$

t_P = Predicted time from engine control valve start signal to hypergol switch dropout for stage test (seconds)

t = Acceptance test time from engine control valve start signal to hypergol switch dropout (seconds) at inlet conditions of $P_{I\phi}$ and P_{IF} (psig)

$\hat{t}$ = Standardized time from engine control valve start signal to hypergol switch dropout (seconds) calculated in step a

$P_{I\phi}$ = Pre-start oxidizer pump inlet pressure during acceptance test (seconds)

P_{IF} = Pre-start fuel pump inlet pressure during acceptance test (seconds)

f = Function of

3-24. After the predicted time from engine control valve start signal to hypergol switch dropout has been calculated by Method 1, 2, or 3, the predicted stage time from engine control valve start signal to 90 percent (1,370K) of rated thrust may be calculated. In the stage, the predicted time from hypergol switch dropout to 100 psig chamber pressure is 0.425 second.

Predicted time from engine control valve start signal to 90 percent thrust $= t_P + 1.100$ seconds

t_P = Predicted time from engine control valve start signal to hypergol switch dropout.

3-25. FUEL PUMP IMPELLER BACKCASING PRESSURE RE-ORIFICING TECHNIQUE.

3-26. RE-ORIFICING WITH NO CHANGE IN FUEL PUMP OPERATING CONDITIONS. If the fuel pump inlet pressures and speed are not to be changed between the latest test and the next test, use the following equation to re-orifice the balance cavity supply line to target for fuel impeller backcasing pressure of 250 psig:

$$D_2 = \sqrt{0.15634 - \frac{P_1}{1599} + D_1^{\ 2}}$$

D_1 = Supply orifice diameter from latest test

P_1 = Fuel impeller backcasing pressure from latest test

D_2 = Supply orifice diameter to be used on next test

3-27. RE-ORIFICING WITH CHANGES IN FUEL PUMP INLET CONDITIONS. If the fuel pump inlet pressure for the next test is to be different from the fuel pump inlet pressure of the latest test, the fuel impeller backcasing pressure measured on the latest test should be projected to that which would have occurred if the test had been run under the new inlet pressure. This corrected pressure may then be used in the re-orificing procedure outlined in paragraph 3-25. Calculate the corrected fuel impeller backcasing pressure using the following equation:

$$P_{BCN} = P_{DFN} - \left[\frac{P_{DFL} - P_{BCL}}{P_{DFL} - P_{IFL}}\right] \left(P_{DFN} - P_{IFN}\right)$$

P_{DFL} = Fuel discharge pressure observed on latest test

P_{IFL} = Fuel inlet pressure observed on latest test

P_{BCL} = Fuel impeller backcasing pressure observed on latest test

P_{DFN} = Fuel discharge pressure expected on next test

P_{IFN} = Fuel inlet pressure expected on next test

P_{BCN} = Fuel impeller backcasing pressure corrected for new inlet conditions

The new orifice diameter may then be calculated using the re-orificing equation (paragraph 3-26), with $P_{BCN} = P_1$.

3-28. RE-ORIFICING WITH CHANGES IN TURBOPUMP SPEED. If a significant change in turbopump speed (more than 40 rpm) is anticipated between the latest test and the next test, the fuel impeller backcasing pressure from the latest test must then be corrected to new turbopump speed before the re-orificing equation (paragraph 3-26) can be used. The present technique uses past component and engine turbopump fuel discharge pressures, fuel impeller backcasing pressures, fuel inlet pressures, and speed data for the specific turbopump being re-orificed. The fuel impeller backcasing pressure for each test should be corrected to the fuel pump inlet pressure expected on the next engine test, using the equation outlined in paragraph 3-27. This corrected fuel impeller backcasing pressure should be plotted against the turbopump speed observed during that test. The resulting curve determines the corrected fuel impeller backcasing pressure at the turbopump speed expected on the next test. The resulting value of fuel impeller backcasing pressure determines the new fuel impeller backcasing orifice diameter from the equation outlined in paragraph 3-26.

3-29. <u>HEAT EXCHANGER PERFORMANCE EVALUATION AND PREDICTION.</u>

3-30. Heat exchanger performance is determined from operational characteristics of the heat exchanger using data obtained during testing of the heat exchanger. The calculations necessary to determine heat exchanger performance are made in a computer program, which requires data input as listed in figure 3-29. All listed input is required except for the LOX coil outlet pressure. Inclusion of the LOX coil outlet pressure will enable the LOX coil resistance to be calculated. Standardized data are included because they are required data; however, they normally are not changed from the nominal values listed in figure 3-29. Operating data should be obtained from a performance data interval of 3.0 to 3.2 seconds duration that starts at or after 20 seconds of engine effective duration. Output from the program summarizes heat exchanger operation at site conditions, determines coil outlet temperatures at standard inlet conditions, predicts coil outlet temperatures at the target time of a subsequent test, and calculates the diameter of the coil bypas orifice required to achieve the target coil outlet temperature at standard inlet conditions and at the target time of a subsequent test.

	Parameter		
Type of Data	Name	Nominal Value	Units
Identification Data	Engine serial number		
	Heat exchanger serial number		
	Test number		
Test Condition Data	Test duration		Seconds
	Ambient pressure		psi
	Time of slice start		Seconds
Operational Data	Turbine exhaust temperature		°F
	Sea-level turbine exhaust temperature		°F
	LOX coil flowrate		lb/sec
	LOX coil inlet temperature		°F
	LOX coil outlet temperature		°F
	LOX coil outlet pressure (optional)		psia
	Helium coil flowrate		lb/sec
	Helium coil inlet temperature		°F
	Helium coil outlet temperature		°F
Standardized Data	Anticipated additional operation time to target time	35	Seconds
	LOX coil flowrate	4	lb/sec
	LOX coil inlet temperature	-288	°F
	LOX coil outlet target temperature	470	°F
	Helium coil flowrate	0.6	lb/sec
	Helium coil inlet temperature	-345	°F
	Helium coil outlet target temperature	255	°F

Figure 3-29. Heat Exchanger Performance Evaluation and Prediction Input Data Requirements

3-31. HEAT EXCHANGER COMPUTER PROGRAM OPTIONS.

3-32. In addition to the performance evaluations and predictions (paragraph 3-30), the heat exchanger computer program contains the following optional capabilities:

a. Enables predictions to be based upon specified bypass ratios rather than bypass orifice diameters.

b. Enables heat exchanger performance to be predicted with specified alternate bypass orifice diameters.

c. Enables flowrates to be computed from flowmeter nozzle data.

d. Enables average performance to be established from a series of tests.

e. Enables coil outlet temperature data to be adjusted for instrumentation system lag when data is obtained during a transient condition.

3-33 through 3-37. (Deleted)

All data on pages 3-29 through 3-38, figures 3-30 through 3-38 deleted.

3-40. CALCULATIONS INVOLVING A TYPICAL ENGINE.

3-41. For calculations involving a typical engine, the initial values would be the same as the nominal values, as follows:

$F_{E_i} = F_{E_N}$ $\quad P_{a_i} = P_{a_N}$ $\quad T_{F_i} = T_{F_N}$

$\rho_{F_i} = \rho_{F_N}$ $\quad \rho_{O_i} = \rho_{O_N}$

$P_{F_i} = P_{F_N}$ $\quad P_{O_i} = P_{O_N}$

The following are the calculations used to determine the thrust of the engine when operated under the following conditions:

a.	Atmospheric pressure	=	3.90 psia
b.	Fuel temperature	=	75° F
c.	Fuel density	=	50.45 lb/cu ft
d.	Oxidizer density	=	70.90 lb/cu ft
e.	Fuel pump inlet pressure	=	42.00 psia
f.	Oxidizer pump inlet pressure	=	89.55

$$\frac{F_E - 1,522,000}{1,522,000} = \frac{3.90 - 14.696}{14.696}(-0.1458) + \left(\frac{75.00 - 60.00}{60.00}\right)(0.0191) + \left(\frac{50.45 - 50.45}{50.45}\right)(-0.9434) + \left(\frac{70.90 - 71.38}{71.38}\right)(2.1345) + \left(\frac{42.00 - 45.00}{45.00}\right)(-0.0090) + \left(\frac{89.55 - 65.00}{65.00}\right)(0.0544)$$

$$\frac{F_E - 1,522,000}{1,522,000} = (-0.7346)(-0.1458) + (0.2500)(0.0191) + (0.0\quad)(-0.9434) + (-0.0067)(2,1345) + (-0.0667)(0.0090) + (0.3777)(0.0544)$$

$$= +0.1187 \text{ or } +11.87 \text{ percent change}$$

$$F_E = +0.1187\,(1,522,000) + 1,522,000$$

$$= +180,700 + 1,522,000 = 1,702,700$$

The incremental thrust has been found to be 180,700 lb for the conditions stated, yielding a final engine thrust of 1,702,700 lb. Propellant densities may be estimated from measured temperature and pressure data with the aid of figures 3-40 and 3-41. Figure 3-40 presents the relationship between the temperature and density for a nominal cut of RP-1 fuel. When the density of a batch of RP-1 is known at one temperature, the density at another temperature can be determined with the slope of the nominal RP-1 line shown in figure 3-40. The effect of pressure on the density of RP-1 is small and may be ignored for inlet conditions encountered on the engine. Figure 3-41 presents the relationship between liquid oxygen temperature, pressure, and density. Two density-versus-temperature curves are presented to show the effect of varying inlet pressure on oxygen density.

3-42. CALCULATIONS INVOLVING A SPECIFIC ENGINE.

3-43. When the values of actual engine parameters differ from those used as nominal values in the table of influence coefficients, the "delta method" of application of influence coefficients is used. This procedure consists of computing an incremental change of variables rather than a percentage change of these variables. The incremental change is then applied to the actual engine value. This effect can be accomplished by using the equation of the quantities

$$F_{E_i},\ P_{a_i},\ F_i,\ \rho_{O_i},\ P_{F_i},\ \text{and } P_{O_i},$$

which are defined as the actual engine values of these parameters. All other quantities are as defined previously.

3-43A. TEST TREND CORRECTIONS.

3-43B. During a test, the engine exhibits characteristic trends that may be predicted with the use of influence coefficients. Nominal and actual performance values are established during a time interval of 35-38 seconds of burn time. Changes occur in turbine operational characteristics resulting from coke deposits on internal turbine surfaces and thermal expansion in the turbine assembly. Performance changes are calculated for burn time using figures 3-41A and 3-41B. Figure 3-41A presents the percentage change in turbine nozzle area as a

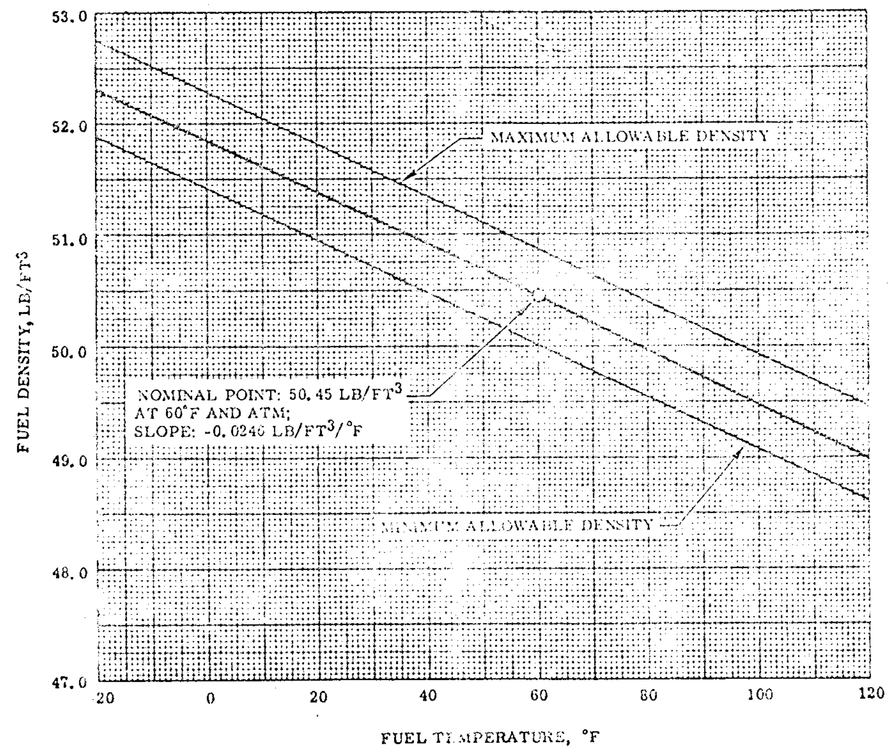


Figure 3-40. RP-1 Fuel Density Versus Temperature

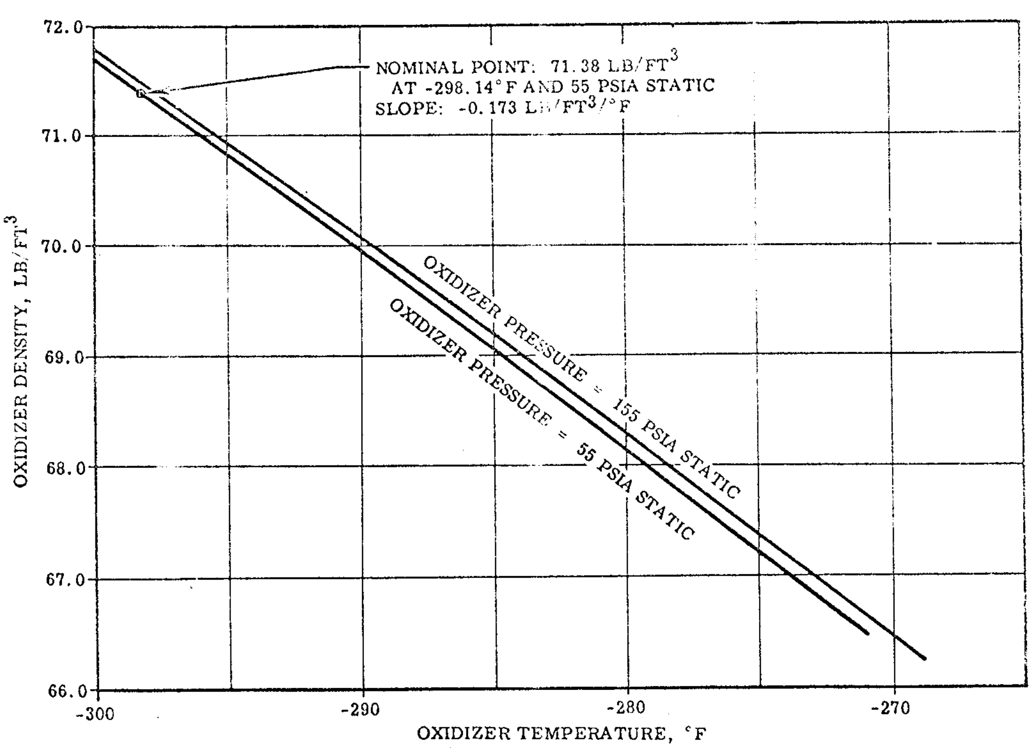
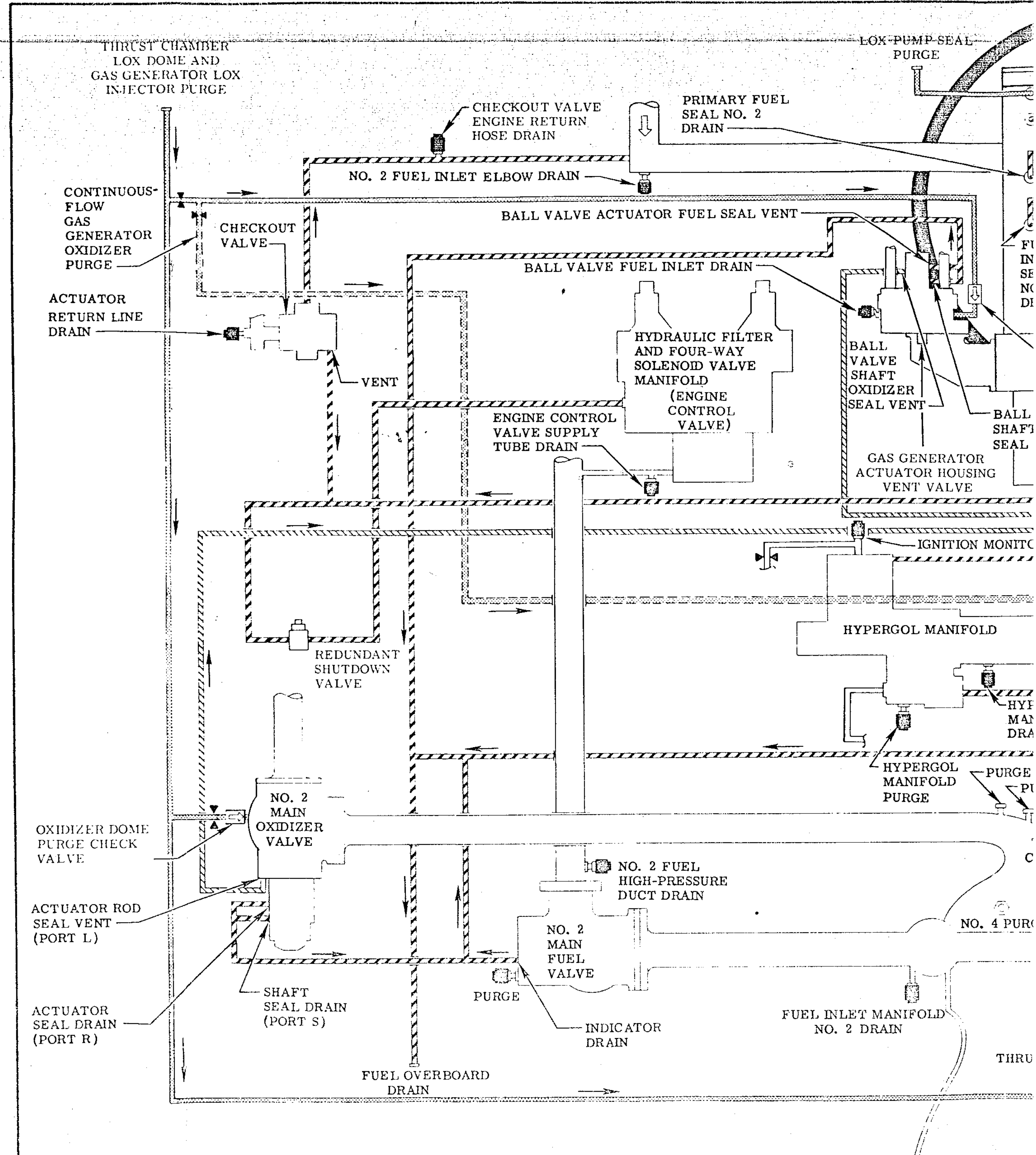


Figure 3-41. Oxidizer Density Versus Temperature



1 ENGINES INCORPORATING MD145 CHANGE

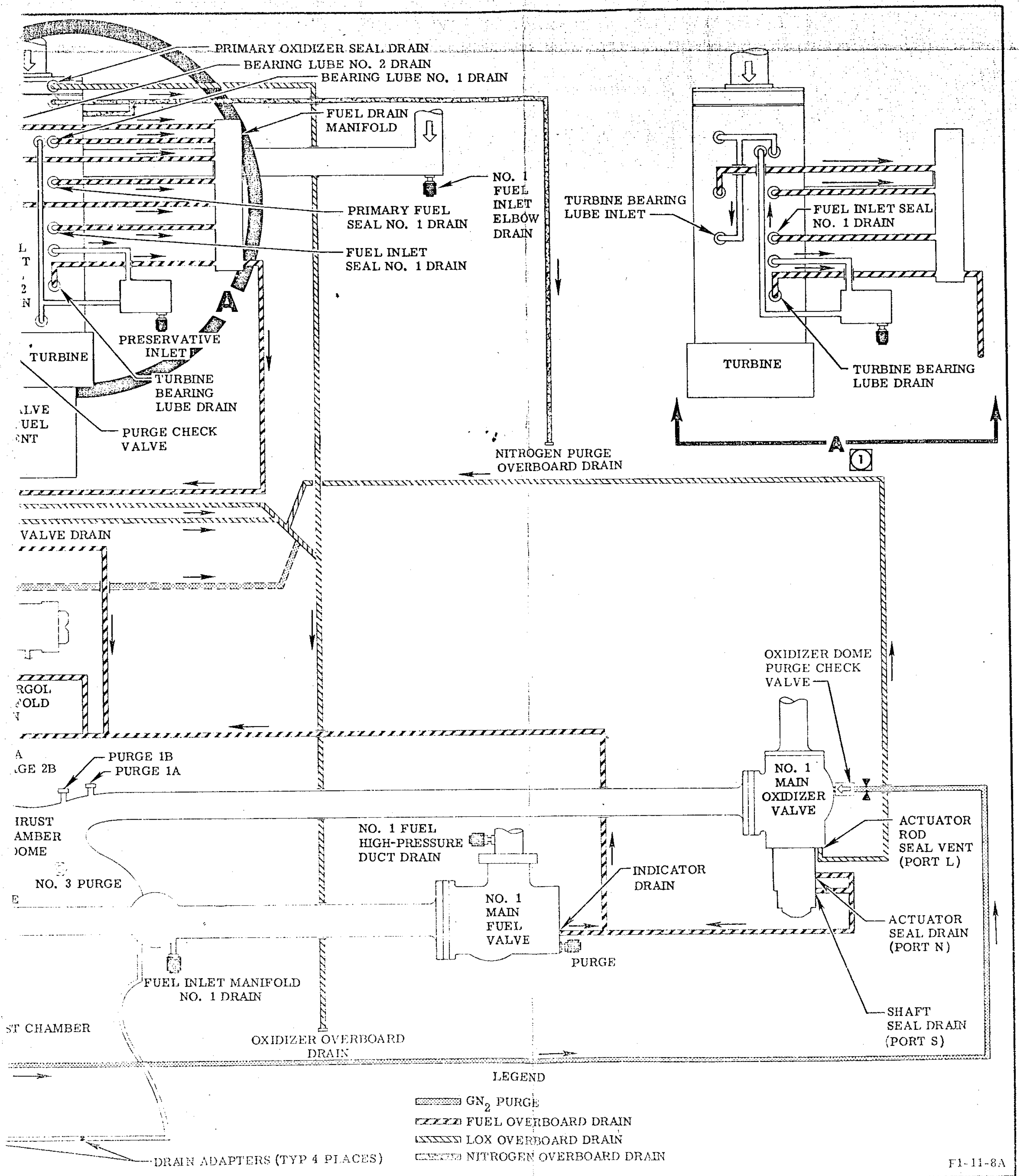


Figure 3-26. Engine Drain and Purge Schematic

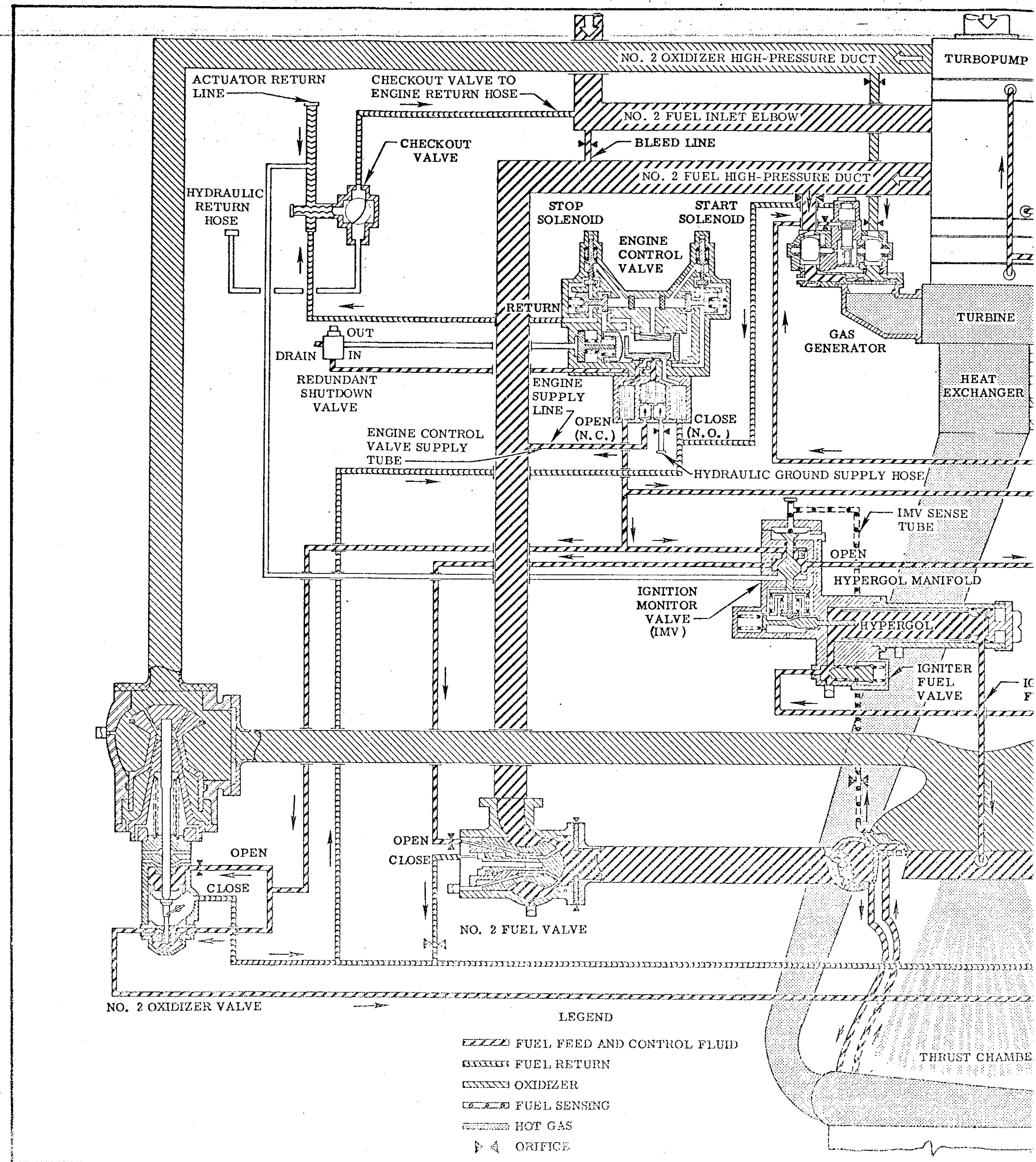
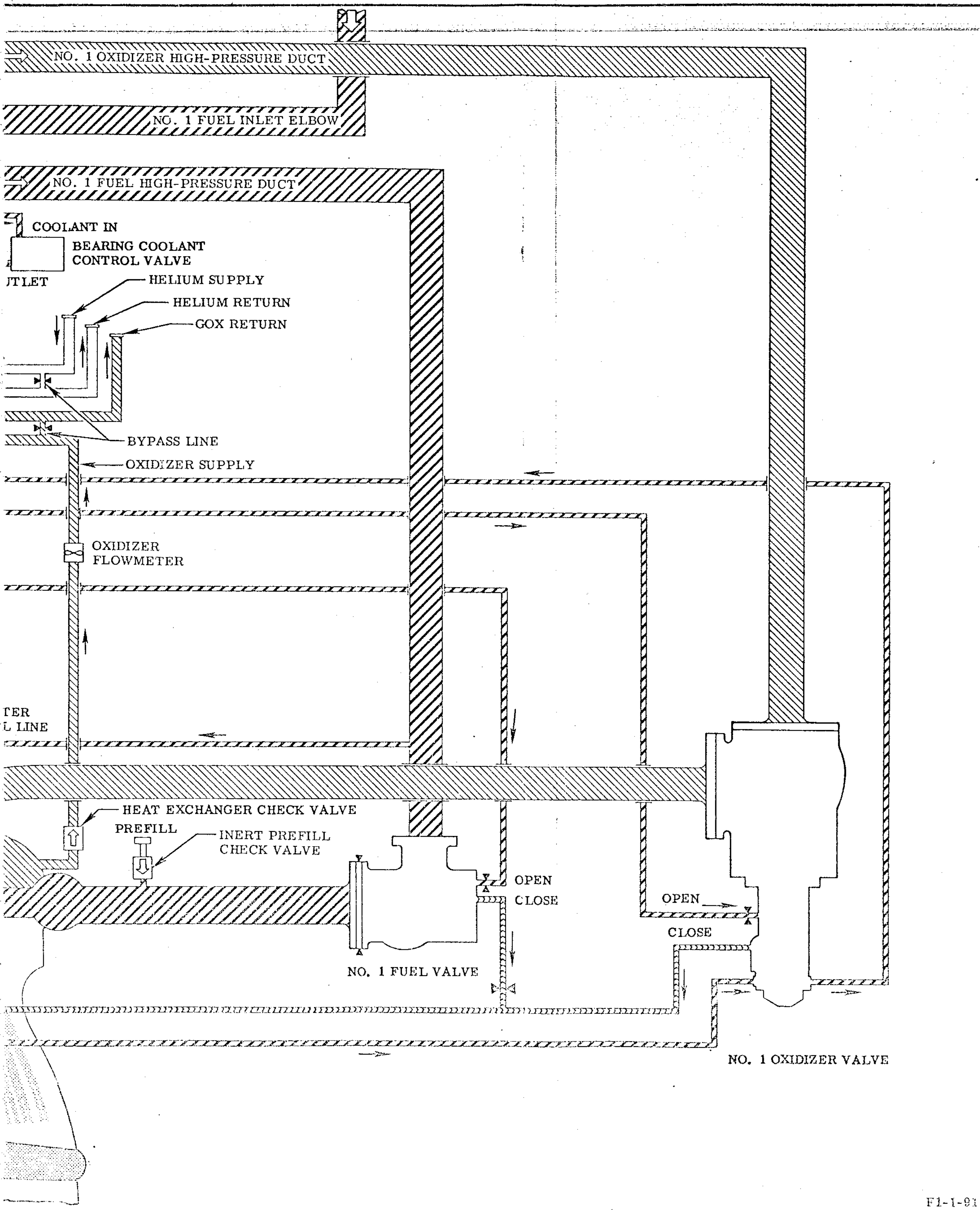
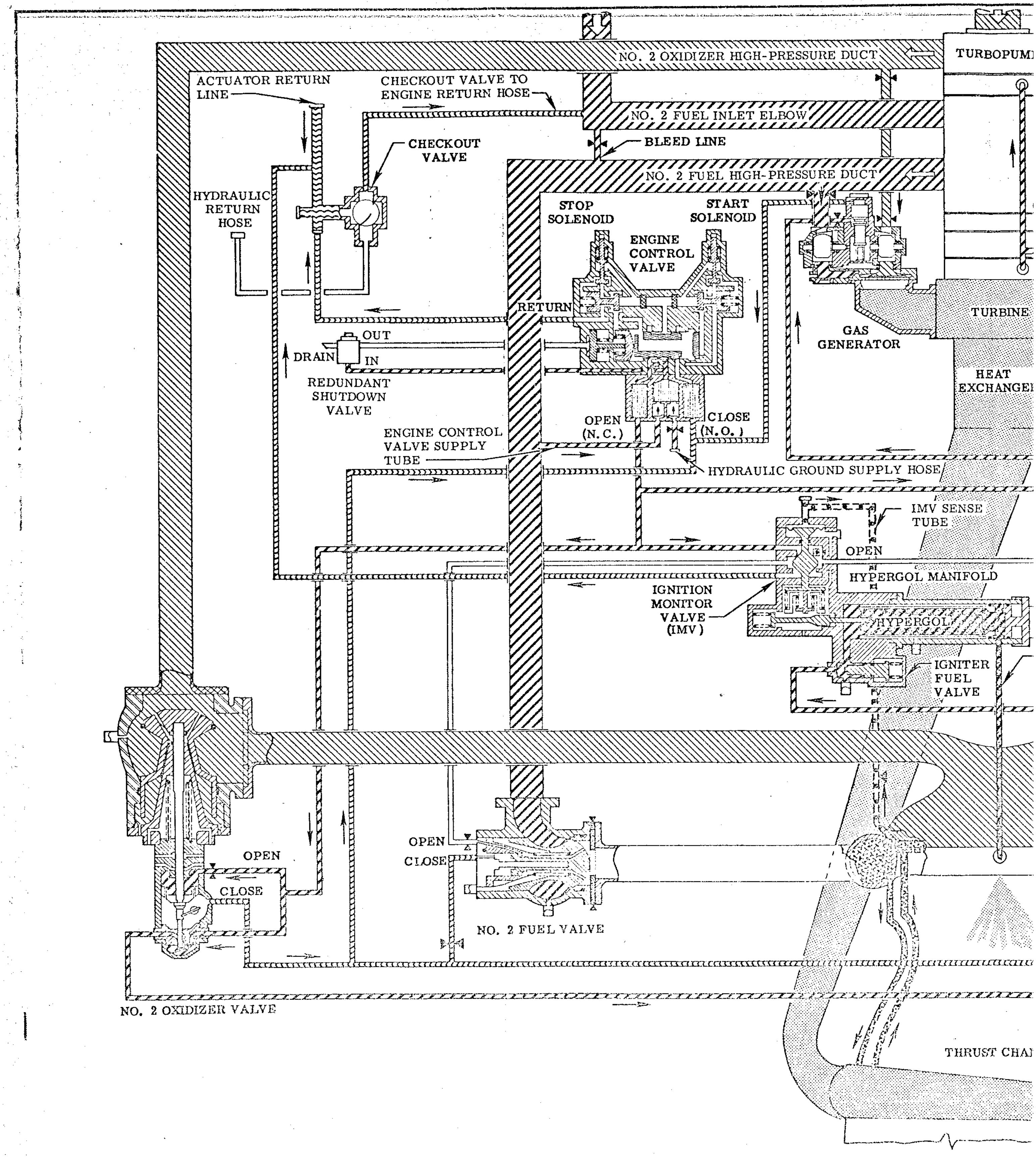


Figure 3-25. Engine Schematic (Mainstage)



NO. 1 OXIDIZER HIGH-PRESSURE DUCT
NO. 1 FUEL INLET ELBOW
NO. 1 FUEL HIGH-PRESSURE DUCT
COOLANT IN
BEARING COOLANT
CONTROL VALVE
HELIUM SUPPLY
HELIUM RETURN
GOX RETURN
BYPASS LINE
OXIDIZER SUPPLY
OXIDIZER
FLOWMETER
HEAT EXCHANGER CHECK VALVE
PREFILL
INERT PREFILL
CHECK VALVE
OPEN
CLOSE
OPEN
CLOSE
NO. 1 FUEL VALVE
NO. 1 OXIDIZER VALVE

F1-1-91



NO. 2 OXIDIZER HIGH-PRESSURE DUCT
TURBOPUMP
ACTUATOR RETURN LINE
CHECKOUT VALVE TO ENGINE RETURN HOSE
NO. 2 FUEL INLET ELBOW
CHECKOUT VALVE
BLEED LINE
NO. 2 FUEL HIGH-PRESSURE DUCT
HYDRAULIC RETURN HOSE
STOP SOLENOID
START SOLENOID
ENGINE CONTROL VALVE
RETURN
TURBINE
GAS GENERATOR
OUT
DRAIN
IN
HEAT EXCHANGER
REDUNDANT SHUTDOWN VALVE
OPEN (N.C.)
CLOSE (N.O.)
ENGINE CONTROL VALVE SUPPLY TUBE
HYDRAULIC GROUND SUPPLY HOSE
IMV SENSE TUBE
OPEN
HYPERGOL MANIFOLD
IGNITION MONITOR VALVE (IMV)
HYPERGOL
IGNITER FUEL VALVE
OPEN
CLOSE
OPEN
CLOSE
NO. 2 FUEL VALVE
NO. 2 OXIDIZER VALVE
THRUST CHA

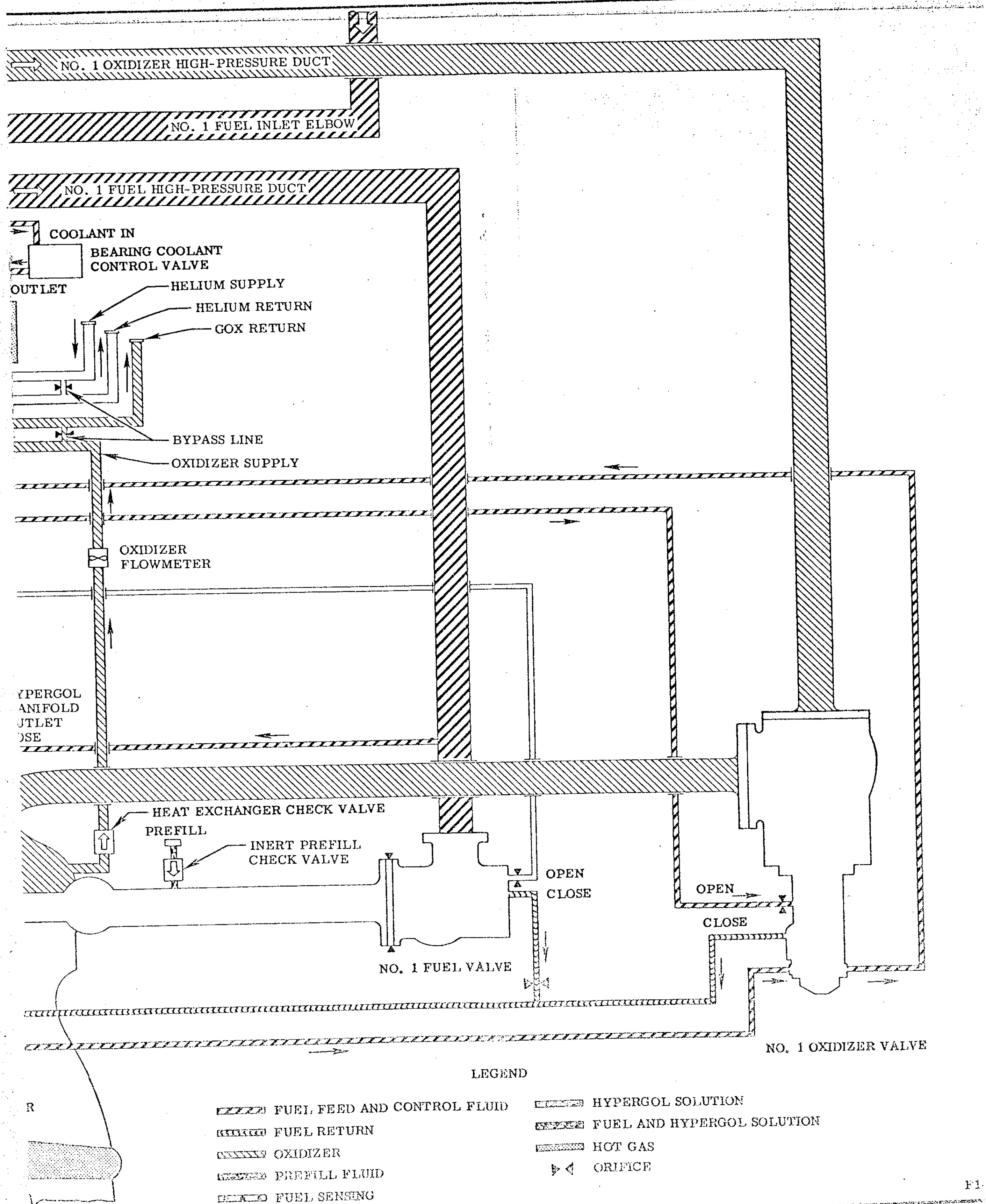


Figure 3-24. Engine Schematic (Ignition)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID,in.	Pressure, psig	Temperature, °F	Number of Fasteners
		OXIDIZER PURGE AND DRAIN JOINTS						
B3,D1, D5,F1, F6	OD-4	Oxidizer Drain Line	F	S	0.25	10	-100 to +100	1
D5	OD-8	Oxidizer Drain Line	F	S	0.50	10	-100 to +100	1
D5 E5	OD-17	Oxidizer Overboard Drain Line	NA	TS	1.350	10	-100 to +100	4
F1 F6	OD-19	No. 1 and 2 LOX Valve Actuator Shaft Drain	KB	TS	0.451	10	-100 to +100	1
A4	OD-20	Oxidizer Drain Line	F	S	1.25	10	-100 to +100	1
B3	OD-21	Gas Generator Ball Valve LOX Vent Port (2 seals)	KB	TS	0.451	10	-100 to +100	1
		NITROGEN PURGE AND DRAIN JOINTS						
H7	N-1	Crossover to LOX Dome and Gas Generator Purge	GO	VA	0.735	1,000	0-130	4
H3	N-2	Purge Supply Line to No. 2 MLV	GO	VA	0.735	1,000	0-130	4
F1 F7	N-3	Purge Line to No. 1 and 2 Check Valves (2 seals)	GO	VA	0.735	1,000	0-130	4
B4	N-4	Purge Line to GG Ball Valve Check Valve	NA	TS	1.026	1,000	0-130	4
A3	N-5	Pump LOX Seal Purge Crossover Line to Hard Line	GO	VA	1.125	100	0-130	4
A4 B1	N-6	Hard Line Joint (Pump LOX Seal Purge)	GO	VA	0.571	100	0-130	4
B1	N-9	Gas Generator Bypass Oxidizer Manifold Purge	GO	VA	0.571	100	0-130	4
A4	N-10	No. 1 Bearing Purge Adapter to Pump	OR	BN	0.468	100	0-130	1
A4	N-11	No. 1 Bearing Purge Line to Adapter Fuel Pump	OR	BN	0.426	100	0-130	1

Figure 2-27. Purge and Drain Joint and Seal Schematic (Sheet 2 of 4)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
		NITROGEN PURGE AND DRAIN JOINTS (continued)						
F4	N-13	Calip Switch Checkout Line	OR	VA	0.351	1,090	0-130	1
B1	N-14	Gas Generator Bypass Oxidizer Manifold Purge	KB	TS	0.577	10-400	0-130	1
A3	N-17	Purge to Crossover (Insulation)	GO	VA	0.735	175	0-130	4
C6	N-18	Purge Overboard Drain Line	OR	SN	0.688	10	0-130	4
B1	ND-6	Purge Drain Lines	F	S	0.375	10	0-130	1
A4	ND-8	Purge Drain Lines	F	S	0.50	10	0-130	1
		FUEL PURGE AND DRAIN JOINTS						
A4, B4, C2, C3, F1, F6, F7, G2, G6	FD-4	Fuel Drain Lines	F	S	0.25	10	0-130	1
[illegible], B4, C2, D3, E4, F1, G2, G6, G7	FD-6	Fuel Drain Lines	F	S	0.375	10	0-130	1
A4, B4, D2, E2, E4, G2, G6, B6, B7	FD-8	Fuel Drain Lines	F	S	0.50	10	0-130	1
E2, E4	FD-10	Fuel Drain Lines	F	S	0.625	10	0-130	1
D2, E2	FD-12	Fuel Drain Lines	F	S	0.75	10	0-130	1
D2	FD-16	Fuel Drain Lines	F	S	1.0	10	0-130	1
A5, B7 B5, C7 E2	FD-17	Drain Manifold Cover and Outlet Line (3 seals)	GO	VA	2.00	10	0-130	4

Figure 2-27. Purge and Drain Joint and Seal Schematic (Sheet 3 of 4)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners

FUEL PURGE AND DRAIN JOINTS (continued)

Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
B4, C6	FD-19	Turbine Bearing Lube to Drain Manifold (3 seals)	GO	VA	0.735	10	0-130	4
A4, B6, B7	FD-23	Fuel Inlet Drain Lines (4 seals)	OR	VA	0.924	10	0-130	1
A4, B6	FD-25	Fuel Inlet Lube Bearing Drain Inboard	OR	VA	0.644	10	0-130	1
E4	FD-27	Reducer in Fuel Overboard Drain Line	OR	VA	0.468	10	0-130	1
F1 F6	FD-29	No. 1 and 2 LOX Valve Drain to Valve (4 seals)	KB	TS	0.451	10	0-130	1
A4 A4, B6, B7	FD-31	Primary Fuel Seal Drain No. 1 and 2 (4 seals)	OR	VA	0.644	10	0-130	1
A4	FD-33	Ignition Monitor Valve Vent Drain (3 seals)	OR	VA	0.644	10	0-130	1
G2 G6	FD-35	Main Fuel Valve Vent Drain (4 seals)	KB	GS	0.451	10	0-130	1
E4	FD-37	Igniter Fuel Valve Vent	OR	VA	0.468	10	0-130	1
C1 C2	FD-39	Checkout Valve Actuator and Seat Vents (2 seals)	OR	VA	0.351	10	0-130	1
C1	FD-40	Checkout Valve Actuator and Seat Vents (1 seal)	OR	VA	0.351	10	0-130	1
B4, B7	FD-41	Bearing Lube Drain; Inboard and Outboard and Turbine Bearing Lube Drain Lines (3 seals)	GO	VA	0.735	10	0-130	4
D3	FD-43	Igniter Monitor Valve Vent Drain	OR	VA	0.351	10	0-130	1
C1	FD-45	Gas Generator Ball Valve Cavity Vent	KB	TS	0.451	10	0-130	1
B3	FD-46	Gas Generator Ball Valve Shaft Vent	KB	TS	0.451	10	0-130	1
C1	FD-47	Gas Generator Actuator Vent Port	OR	VA	0.351	10	0-130	1

Figure 2-27. Purge and Drain Joint and Seal Schematic (Sheet 4 of 4)

SECTION III

PERFORMANCE

3-1. SCOPE. This section contains nominal engine performance characteristics, methods for predicting engine variable characteristics, engine influence coefficients, instrumentation parameters used during static tests of a single engine, and flight instrumentation transducer data control and processing. The data is presented as an aid in analyzing and/or determining specific engine performance.

3-2. NOMINAL PERFORMANCE CHARACTERISTICS.

3-3. The nominal performance characteristics contained in the following paragraphs are stated values for optimum engine performance. The allowable tolerance for actual engine performance values are based upon these nominal values.

3-4. NOMINAL ENGINE PERFORMANCE VALUES.

3-5. See figures 3-1 through 3-12A for current nominal engine performance values.

3-6. NOMINAL THRUST CHAMBER PERFORMANCE VALUES.

3-7. See figure 3-13 for nominal thrust chamber performance values.

3-8. NOMINAL TUROBPUMP PERFORMANCE VALUES.

3-9. See figures 3-14 through 3-18 for nominal turbopump values.

Parameter	Value
Thrust	1,522,000 lb
Mixture ratio	2.27 O/F
Specific impulse	265.1 sec 265.3 sec(a)
Rated duration	165 sec
Fuel flowrate	1,755 lb/sec 1,756 lb/sec(a)
Oxidizer flowrate	3,984 lb/sec 3,981 lb/sec(a)

(a) Engines incorporating MD128 or MD174 change

Figure 3-1. Nominal Engine Performance Values at Sea Level and Standard Turbopump Inlet Conditions

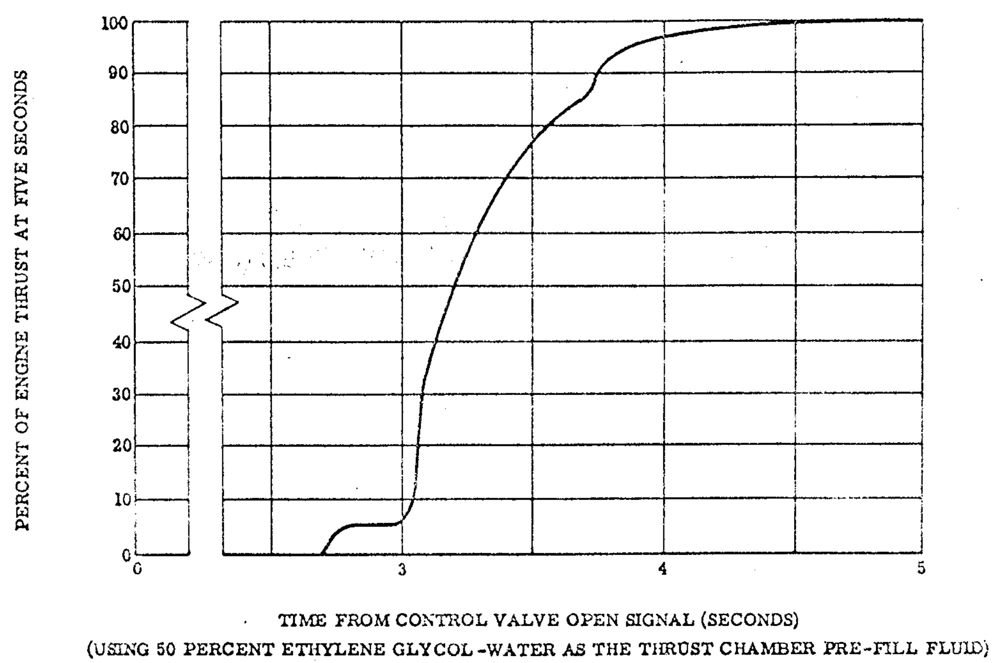


Figure 3-2. Nominal Thrust Buildup Characteristics

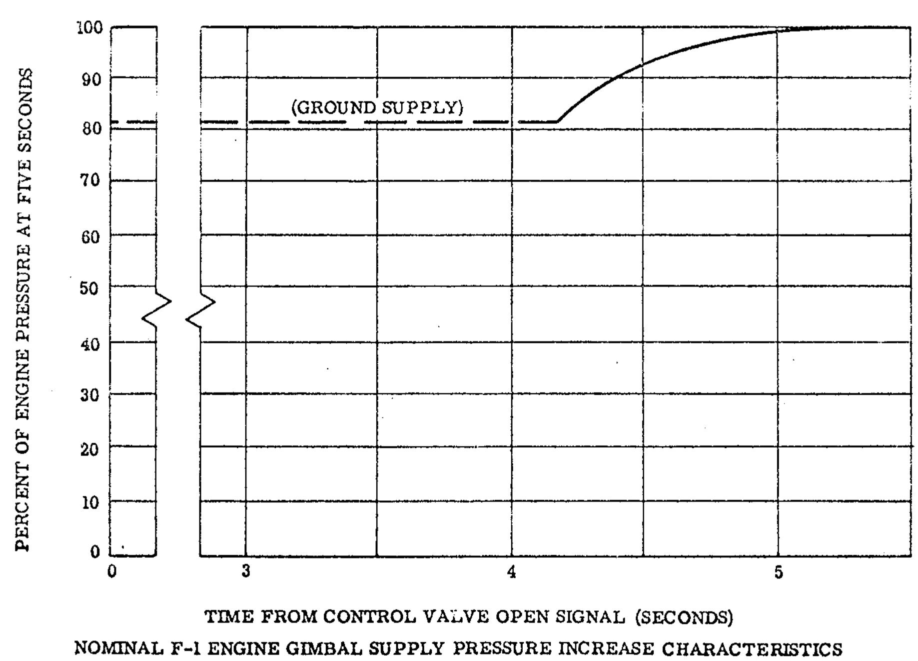


Figure 3-3. Gimbal Buildup Characteristics

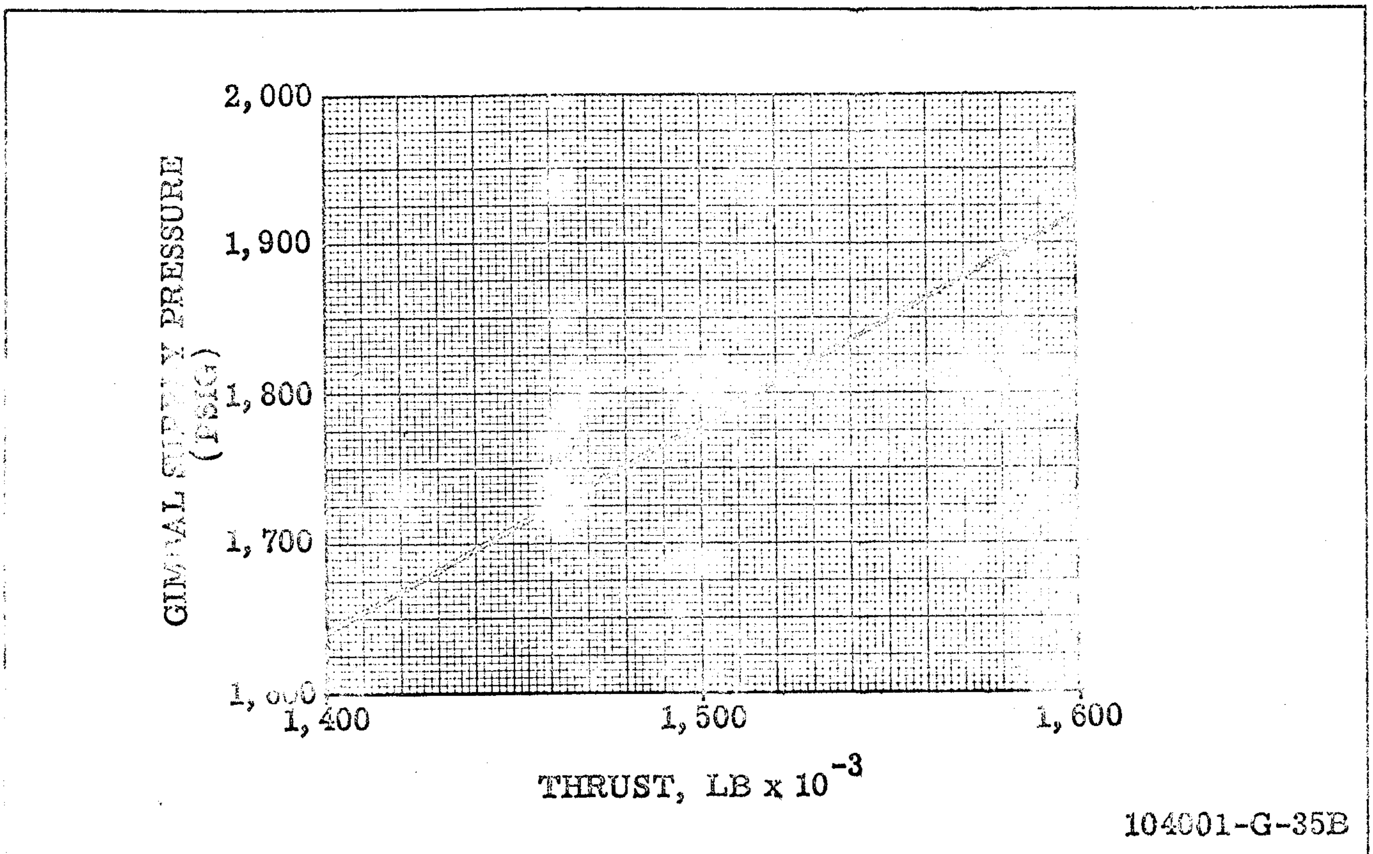


Figure 3-4. Gimbal Supply Pressure Versus Sea-Level Thrust

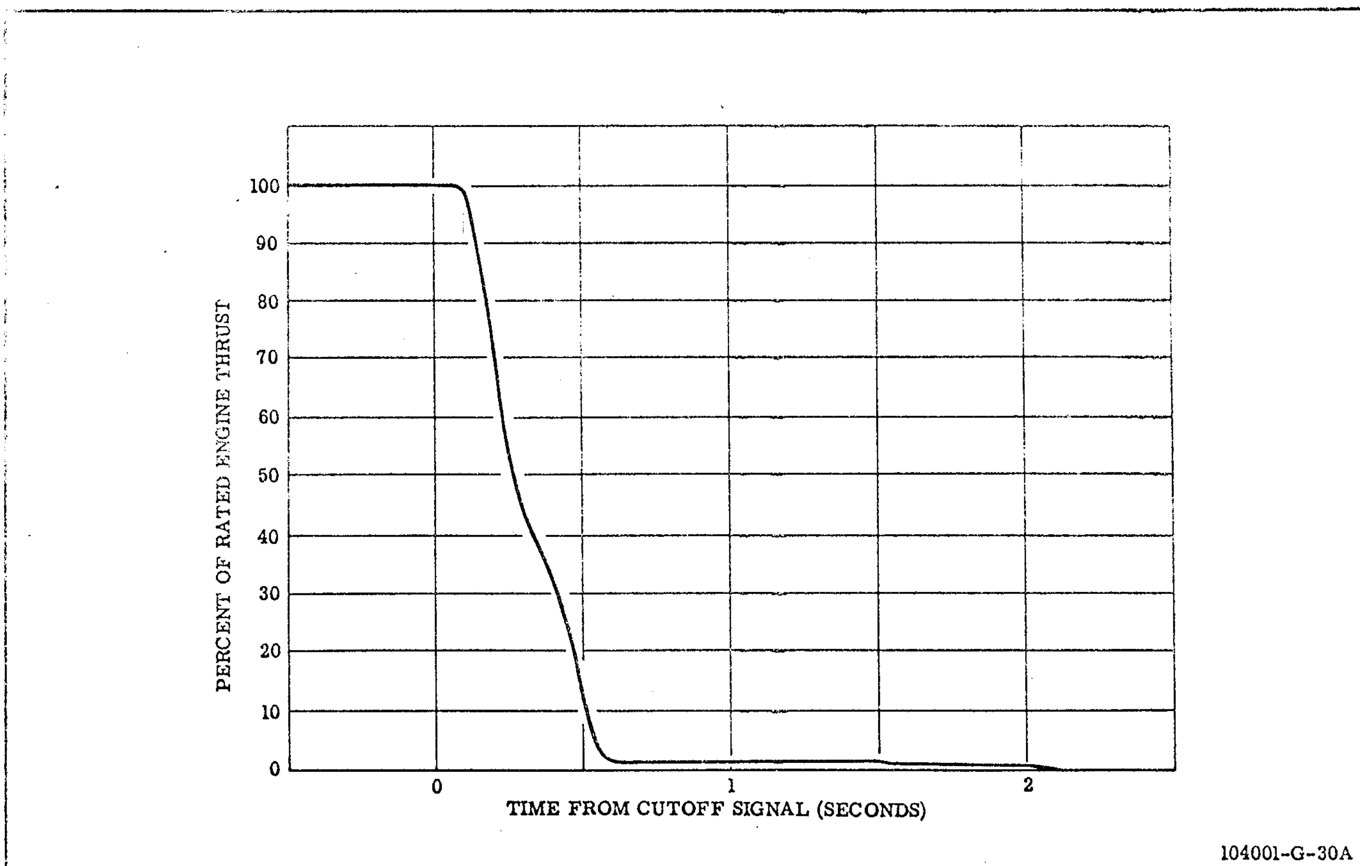


Figure 3-5. Nominal Thrust Decay Characteristics

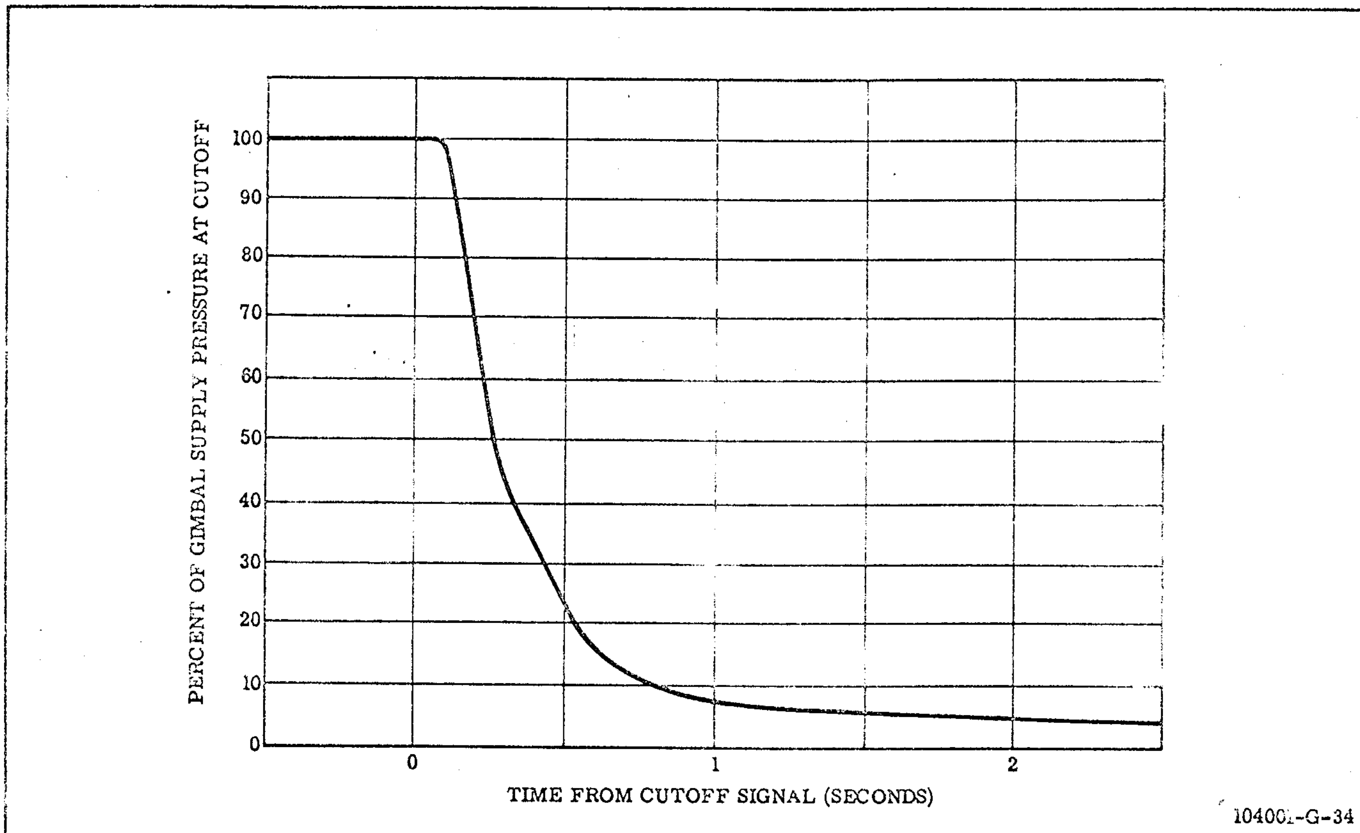


Figure 3-6. Nominal Gimbal Supply Pressure Decrease Characteristics

Figure 3-7 deleted.

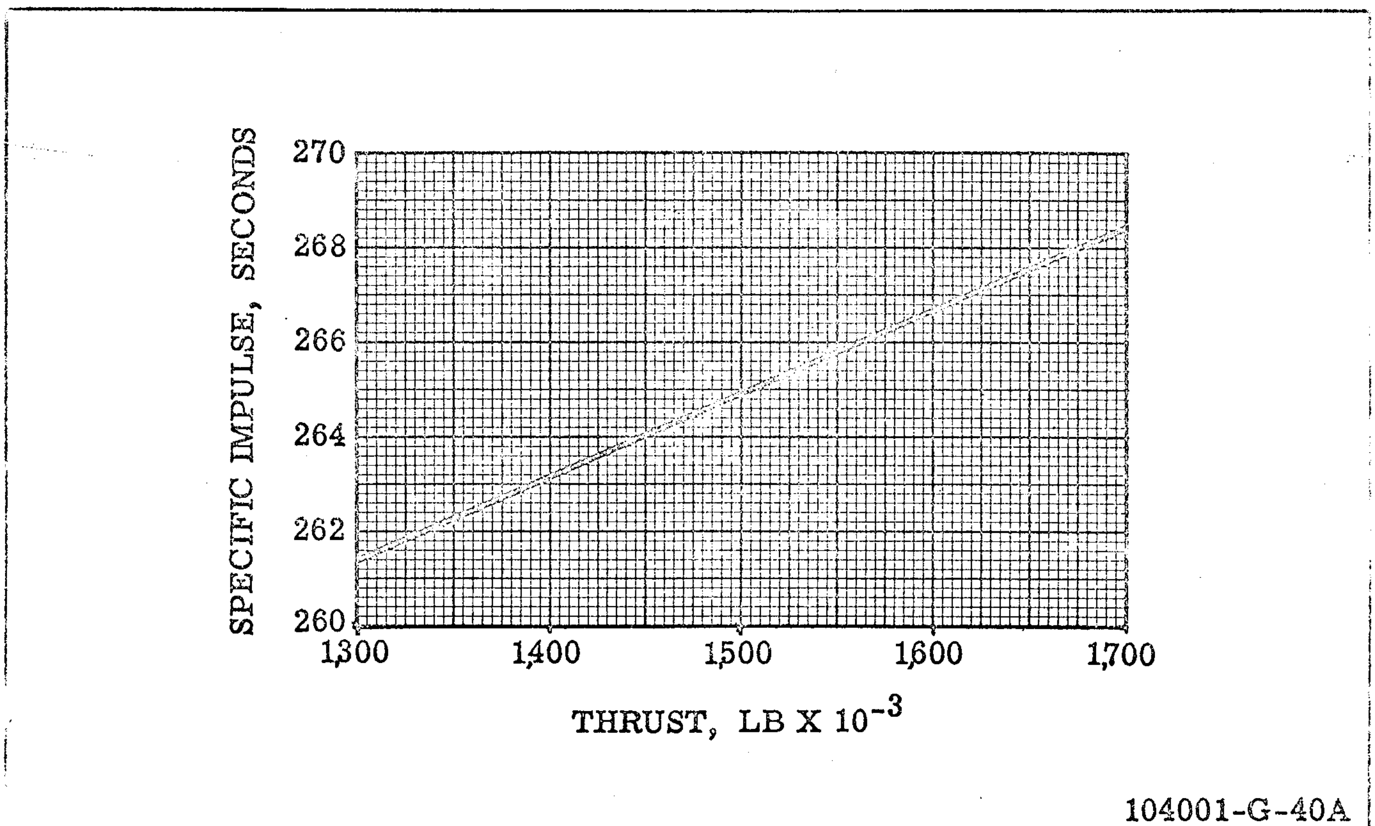
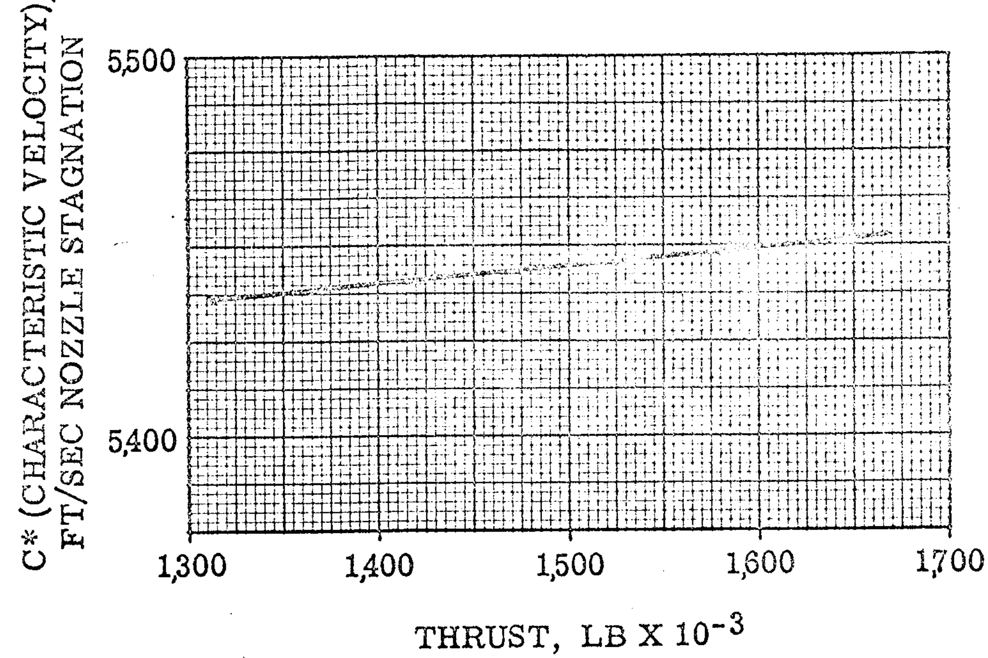


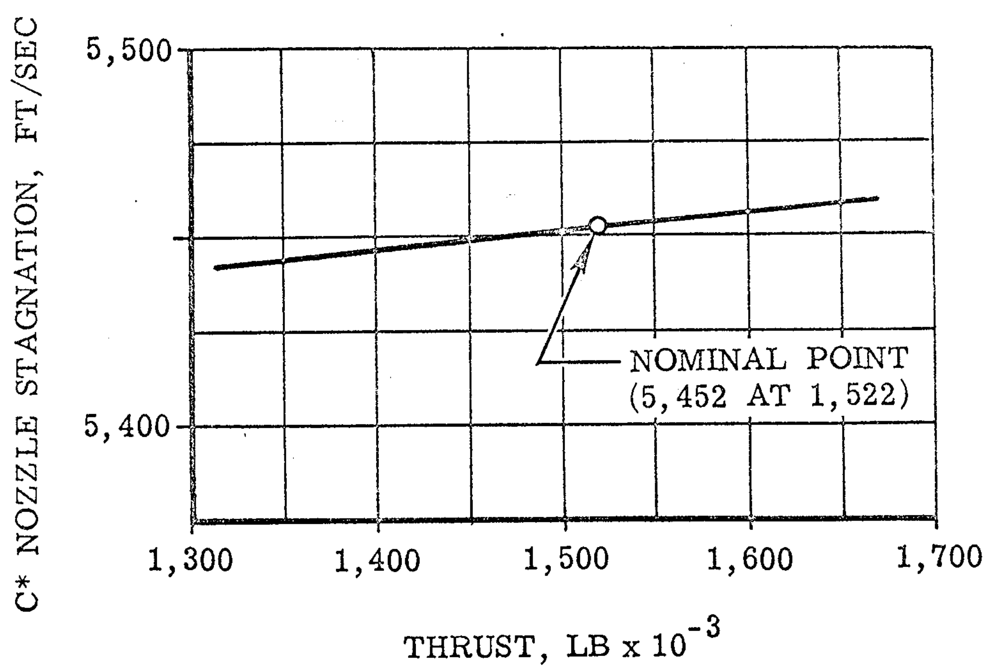
Figure 3-8. Sea-Level Specific Impulse Versus Thrust at Nominal Mixture Ratio and Temperature

Figure 3-9 deleted.



104001-G-41

Figure 3-10. Sea-Level Characteristic Velocity Versus Thrust at Nominal Mixture Ratio and Temperature (Engines Not Incorporating MD128 or MD174 Change)



F1-1-118

Figure 3-11. Sea-Level Characteristic Velocity Versus Thrust at Nominal Mixture Ratio and Temperature (Engines Incorporating MD128 or MD174 Change)

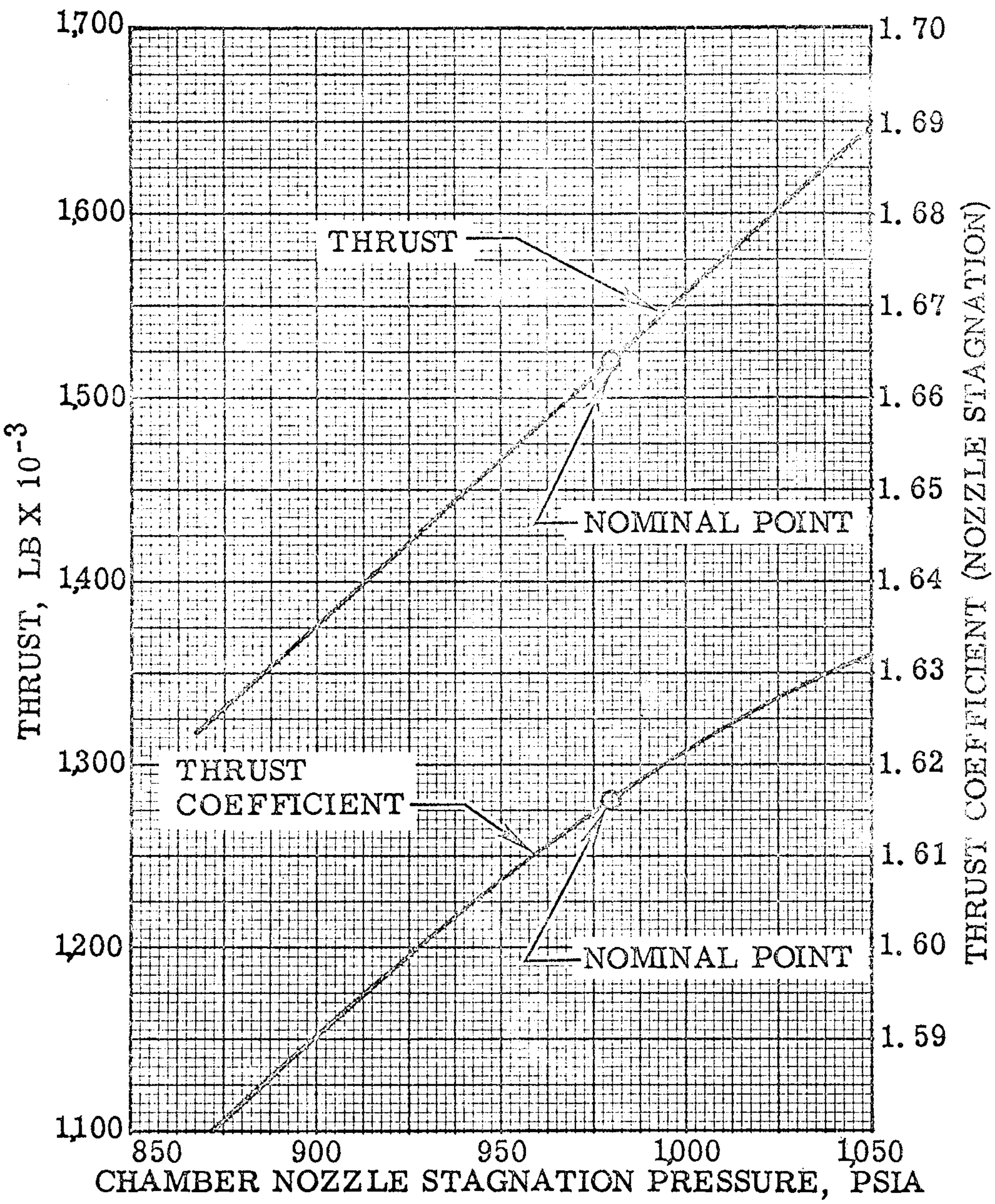


Figure 3-12. Sea-Level Thrust and Thrust Coefficient Versus Chamber Pressure at Nominal Mixture Ratio and Temperature (Engines Not Incorporating MD128 or MD174 Change)

Valve	Switch Times (Seconds)	Potentiometer Times (Seconds)
Oxidizer valve	0.320	0.535
Gas generator ball valve	0.170	
Fuel valve	0.635	0.735

Figure 3-21. Nominal Valve Opening Times for Mainstage

Parameter	Value
Maximum thrust increase for 0.010-second interval, 90-990K lb	50,000 lb
Maximum thrust increase for 0.010-second interval, above 990K lb	21,000 lb
Thrust increase time, 610-1,370K lb	0.59 sec
Oxidizer consumption prior to 90% thrust	620 gal.
Fuel consumption prior to 90% thrust	128 gal.

Figure 3-22. Nominal Thrust Buildup and Approximate Propellant Consumption Values for Mainstage

Parameter	Value[a] (Seconds)
<u>Engine Control Valve Opening Signal to:</u>	
Oxidizer valve starts to open	0.035
Gas generator ball valve starts to open	0.140
Fuel valves start to open	3.570
Time of 100 psig chamber pressure	3.800
Thrust OK pressure switches pickup	4.640

(a) Values are based on S-IC stage application.

Figure 3-22A. Nominal Start Times From Engine Control Valve Open Signal

All data on pages 3-11 through 3-16 deleted.

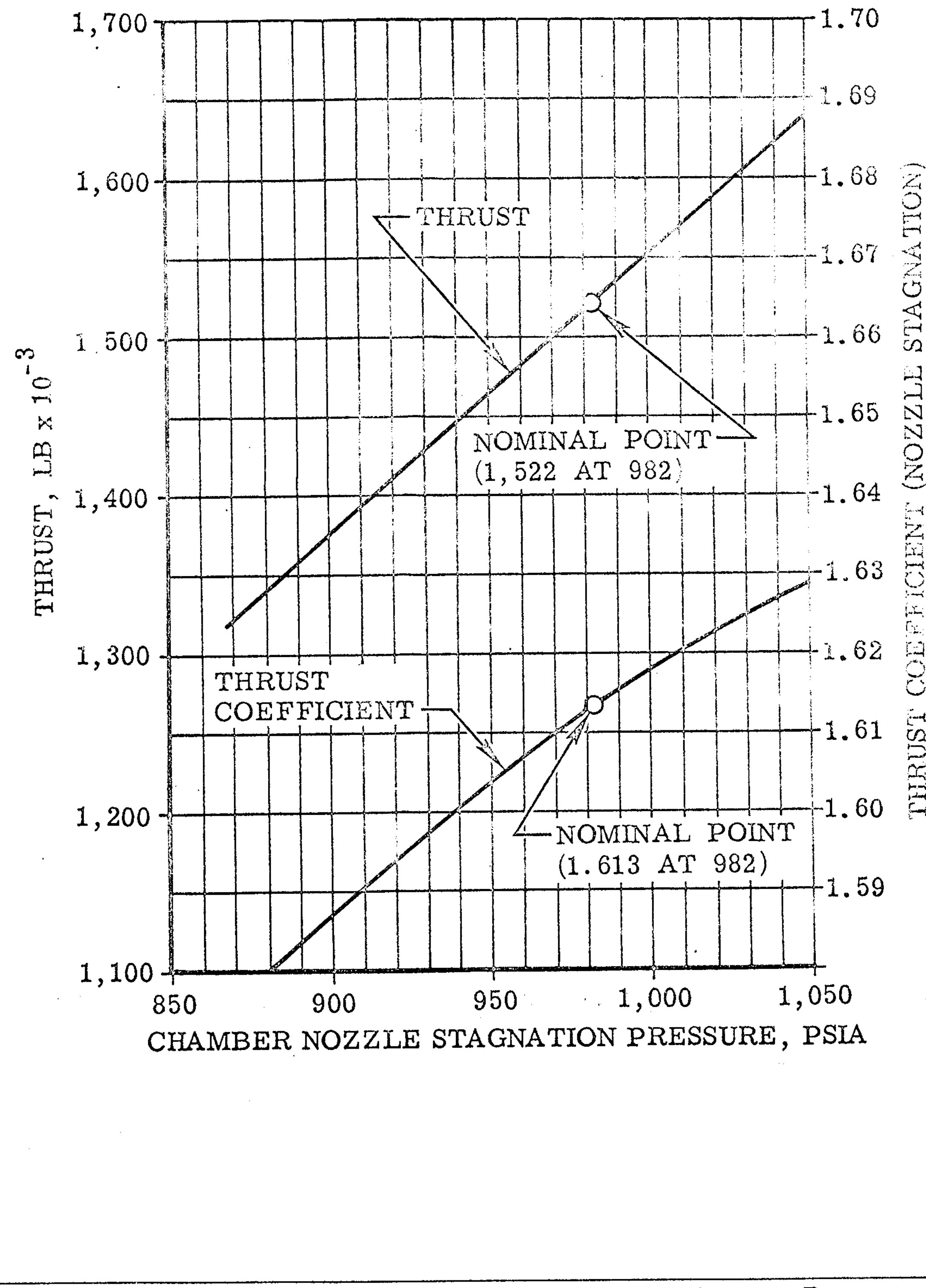


Figure 3-12A. Sea-Level Thrust and Thrust Coefficient Versus Chamber Pressure at Nominal Mixture Ratio and Temperature (Engines Incorporating MD128 or MD174 Change)

Parameter	Value
Thrust at sea level	1,522,000 lb
Expansion area	16:1
Throat area	961.4 sq in.
Thrust chamber pressure	
injector end	1,123 psia 1,125 psia(a)
Nozzle stagnation	980 psia 982 psia(a)
Igniter fuel flowrate	12 lb/sec
Total fuel flowrate	1,633 lb/sec 1,636 lb/sec(a)
Oxidizer flowrate	3,931 lb/sec 3,933 lb/sec(a)
Mixture ratio	2.40 O/F
Characteristic velocity, Nozzle stagnation	5,447 ft/sec 5,451 ft/sec(a)
Throat gas stagnation temperature	5,970° F
Throat gas static temperature	5,328° F
Nozzle exit gas static temperature	1,922° F
Thrust chamber wall temperature at throat	975° F
Cooling jacket prefill volume	105 gal
Oxidizer injector pressure drop	312 psid
Fuel injector pressure drop	96 psid
Cooling jacket pressure drop	265 psid 242 psid(a)

(a) Engines incorporating MD128 or MD174 change

Figure 3-13. Nominal Thrust Chamber Performance Values

Parameter	Value
OXIDIZER PUMP	
Total flowrate	3,986 lb/sec 25,061 gpm 25,063 gpm(a)
Inlet pressure (total)	65 psia
Discharge pressure (total)	1,598 psia 1,602 psia(a)
Required power	30,270 bhp 30,332 bhp(a)
Speed	5,488 rpm 5,492 rpm(a)
Torque	28,967 ft-lb 29,022 ft-lb(a)
FUEL PUMP	
Total flowrate	1,756 lb/sec 15,620 gpm
Inlet pressure (total)	45 psia
Discharge pressure (total)	1,857 psia 1,870 psia(a)
Required power	22,656 bhp 22,814 bhp(a)
Speed	5,488 rpm 5,492 rpm(a)
Torque	21,681 ft-lb 21,829 ft-lb(a)
TURBINE	
Inlet temperature	1,453° F
Exit temperature	1,152° F 1,138° F(a)
Inlet pressure (total)	918 psia 945 psia(a)
Exit static pressure	58 psia
Gas flowrate	172 lb/sec 167 lb/sec(a)
Developed power	52,926 bhp 53,146 bhp(a)
Speed	5,488 rpm 5,492 rpm(a)
Torque	50,649 ft-lb 50,851 ft-lb(a)

(a) Engines incorporating MD128 or MD174 change

Figure 3-14. Nominal Turbopump Performance Values

Figure 3-15 deleted.

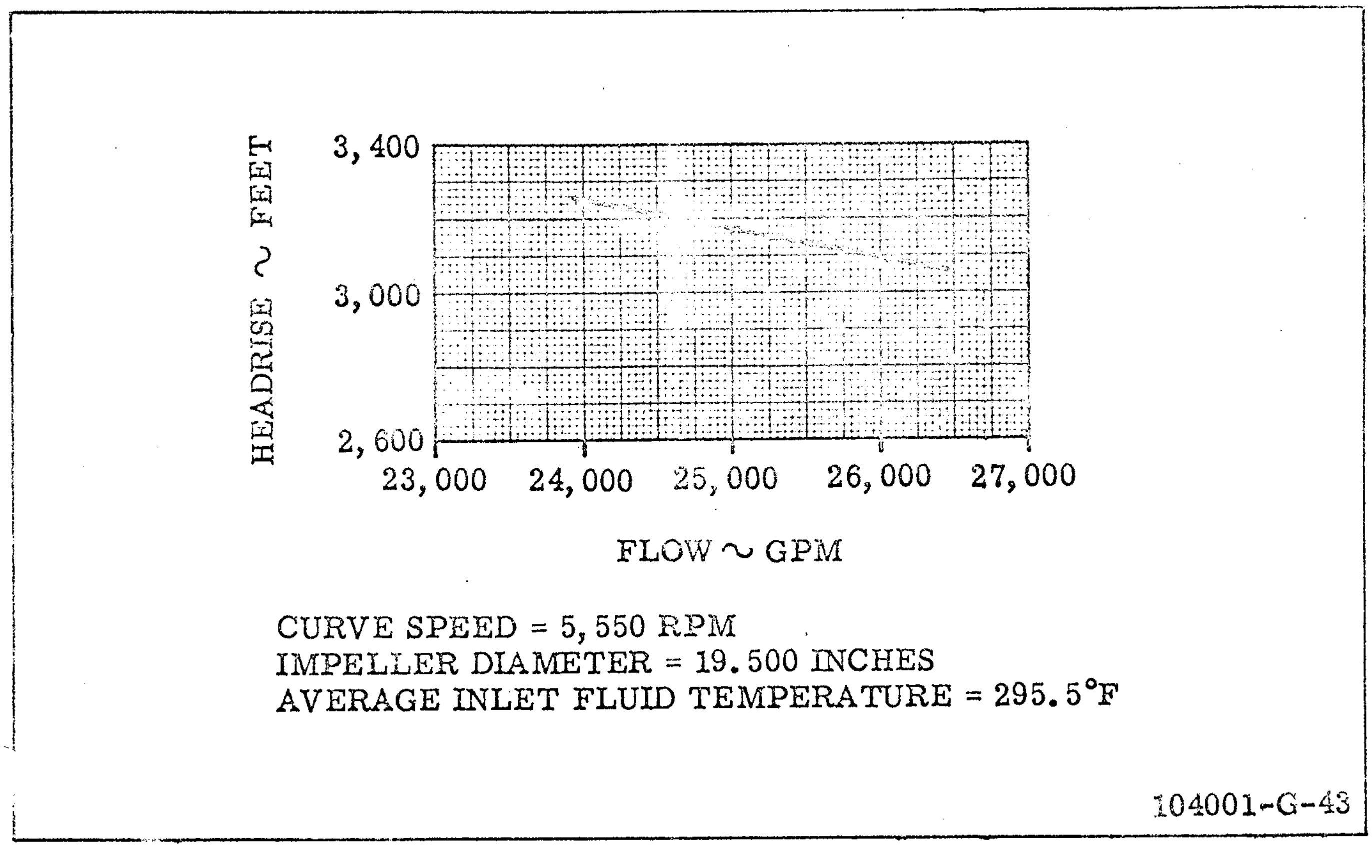
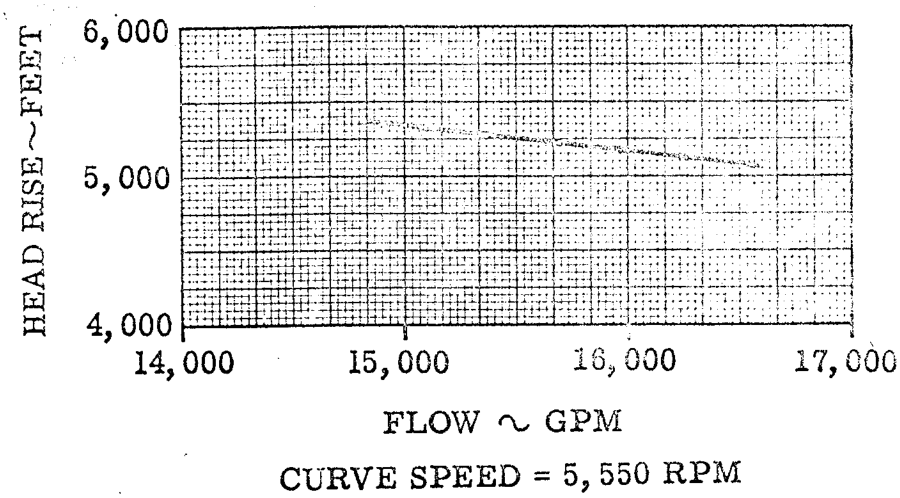


Figure 3-16. Oxidizer Pump Developed Head Versus Volumetric Flowrate

Figure 3-17 deleted.



104C01-G-44

Figure 3-18. Fuel Pump Developed Head Versus Volumetric Flowrate

3-10. NOMINAL GAS GENERATOR PERFORMANCE VALUES.

3-11. See figure 3-19 for nominal gas generator performance values.

Parameter	Value
GAS GENERATOR	
Injector end pressure	956 psia 980 psia (a)
Fuel flowrate	121.1 lb/sec 118.0 lb/sec (a)
Oxidizer flowrate	50.4 lb/sec 49.0 lb/sec (a)
Mixture ratio	0.417 O/F 0.416 O/F (a)
Discharge temperature	1,453° F

(a) Engines incorporating MD128 or MD174 change

Figure 3-19. Nominal Gas Generator Performance Values

3-12. NOMINAL HEAT EXCHANGER PERFORMANCE VALUES.

3-13. See figure 3-20 for nominal heat exchanger performance values.

Parameter	Temperature Range	Nominal Value
Oxygen flowrate	400° to 500° F	4.0 lb/sec
Helium flowrate	185° to 285° F	0.6 lb/sec

Figure 3-20. Nominal Heat Exchanger Performance Values

3-14. ENGINE START CHARACTERISTICS.

3-15. Engine start characteristics (figures 3-21 through 3-26) are presented as nominal values. Refer to R-3896-11 for minimum and maximum values.

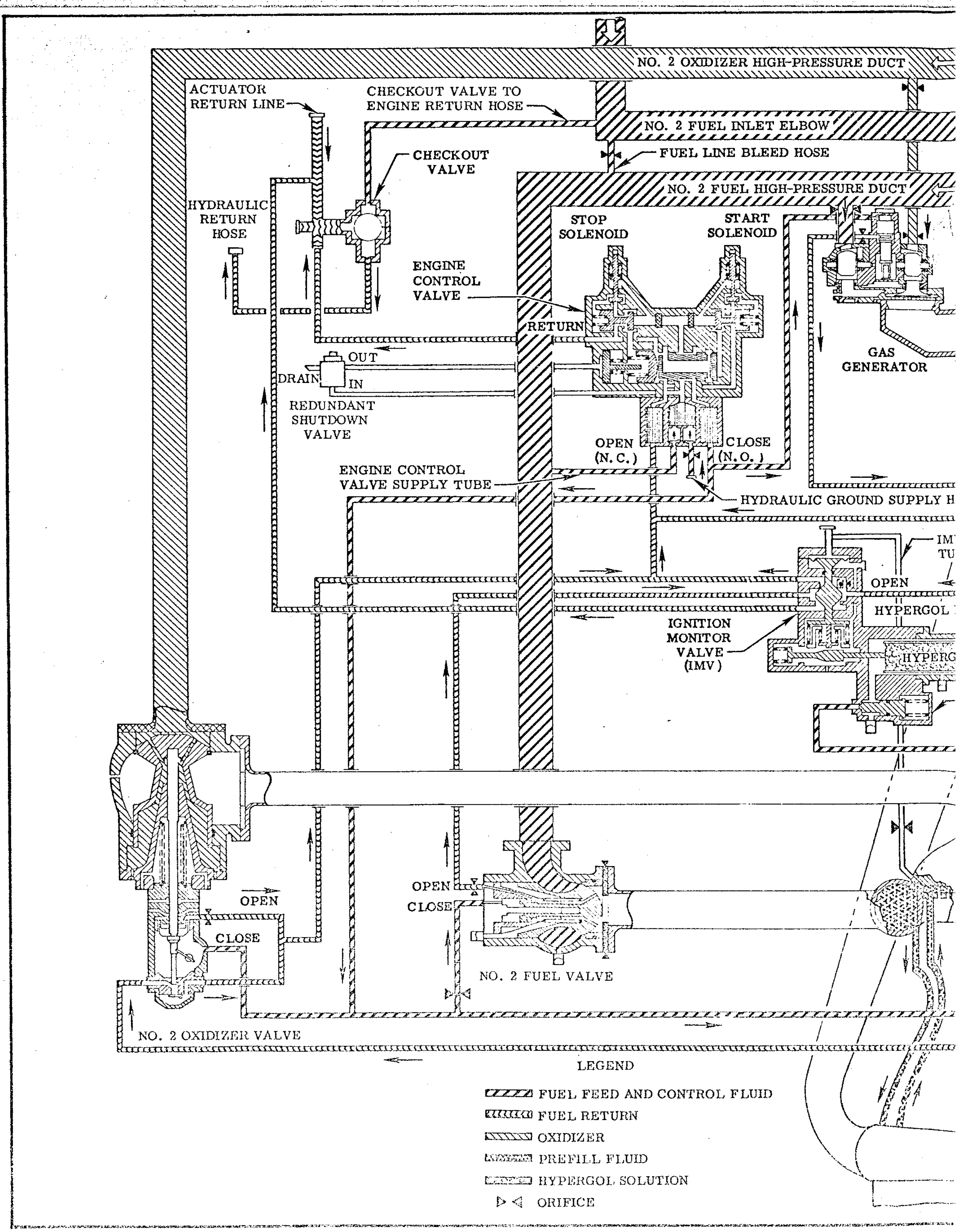

NO. 2 OXIDIZER HIGH-PRESSURE DUCT
ACTUATOR RETURN LINE
CHECKOUT VALVE TO ENGINE RETURN HOSE
NO. 2 FUEL INLET ELBOW
FUEL LINE BLEED HOSE
CHECKOUT VALVE
NO. 2 FUEL HIGH-PRESSURE DUCT
HYDRAULIC RETURN HOSE
STOP SOLENOID
START SOLENOID
ENGINE CONTROL VALVE
RETURN
OUT
DRAIN
IN
REDUNDANT SHUTDOWN VALVE
GAS GENERATOR
OPEN (N.C.)
CLOSE (N.O.)
ENGINE CONTROL VALVE SUPPLY TUBE
HYDRAULIC GROUND SUPPLY H
OPEN
HYPERGOL
IGNITION MONITOR VALVE (IMV)
HYPERG
OPEN
CLOSE
OPEN
CLOSE
NO. 2 FUEL VALVE
NO. 2 OXIDIZER VALVE
LEGEND
FUEL FEED AND CONTROL FLUID
FUEL RETURN
OXIDIZER
PREFILL FLUID
HYPERGOL SOLUTION
ORIFICE

Figure 3-22A deleted.

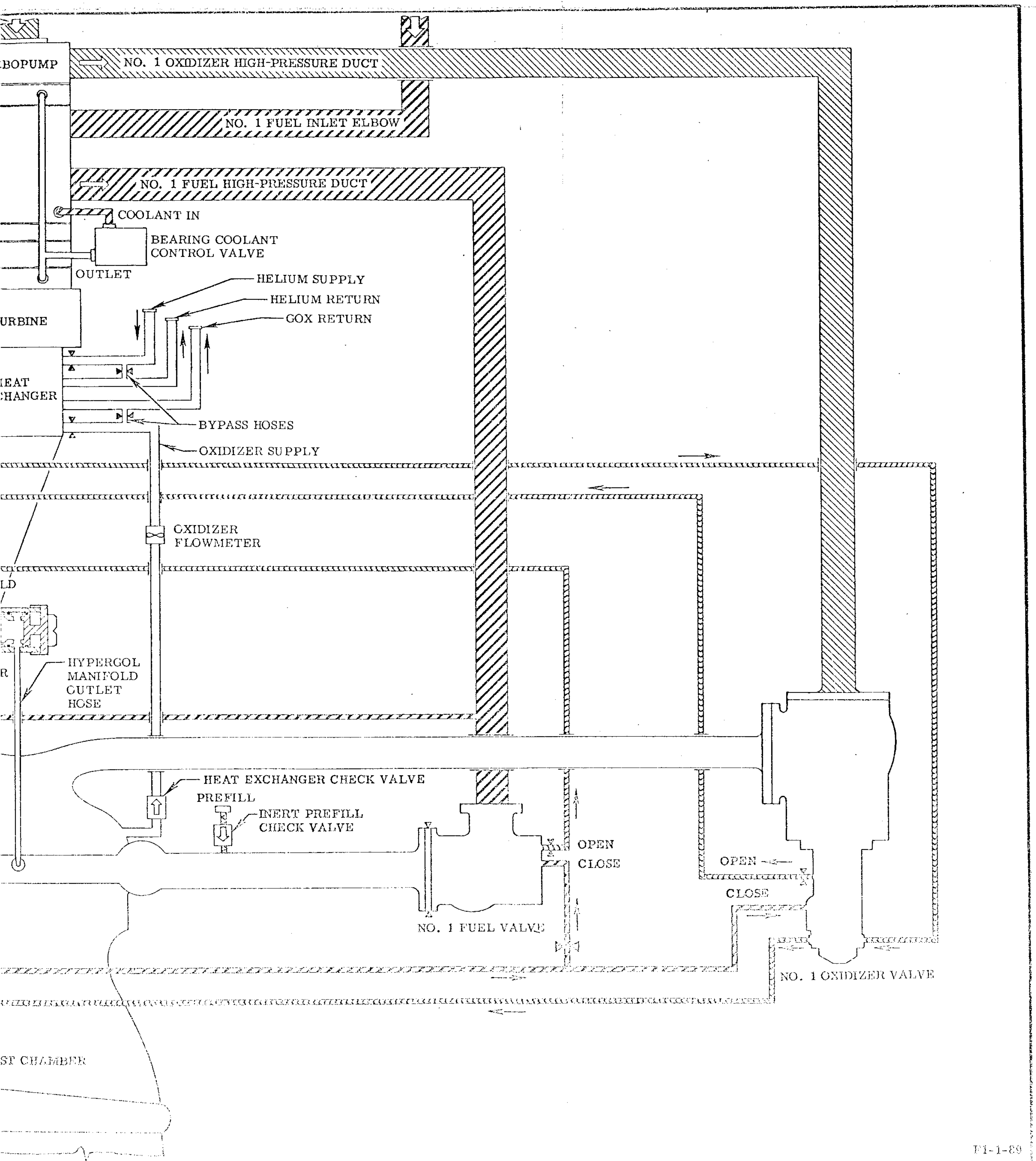
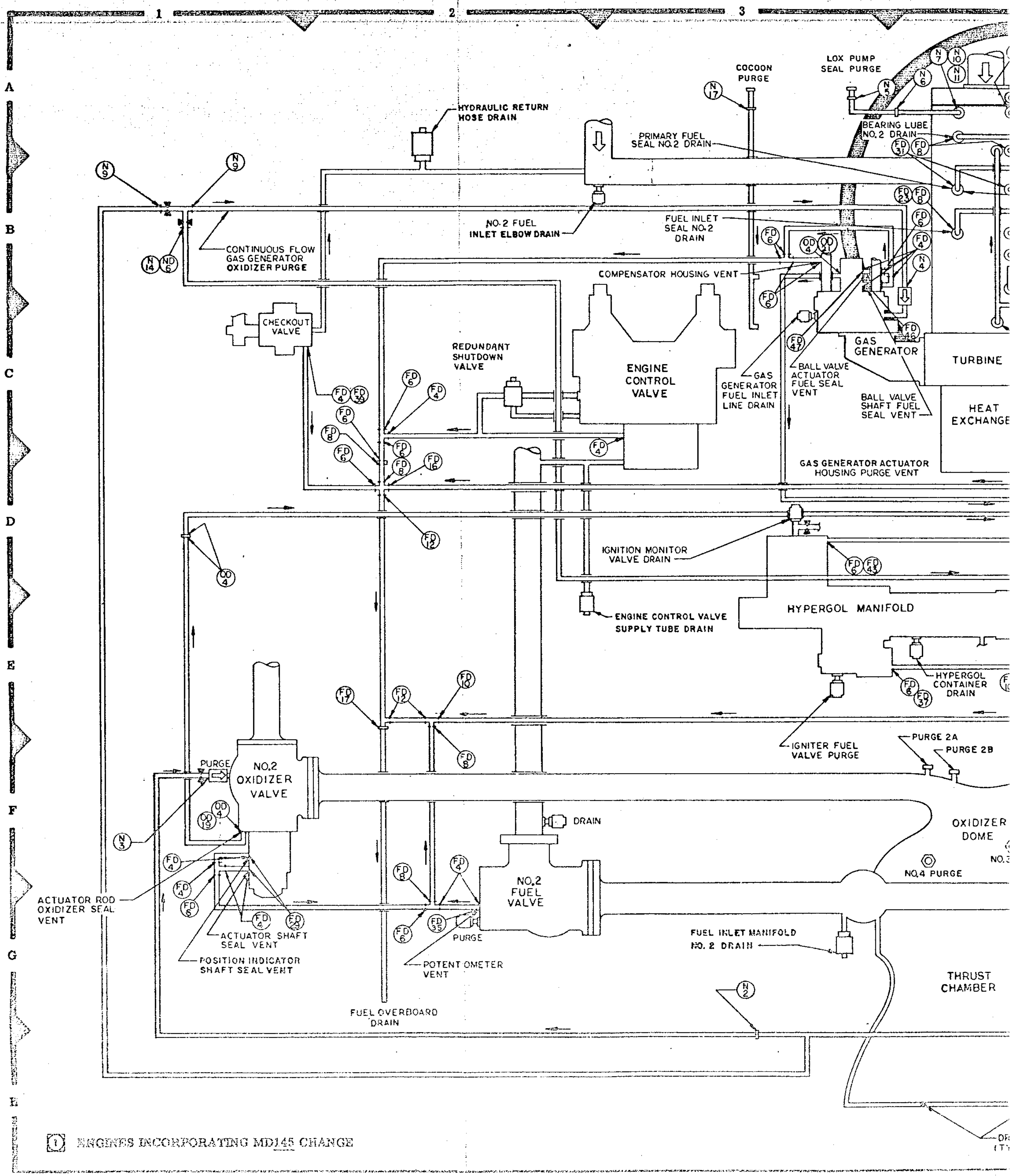
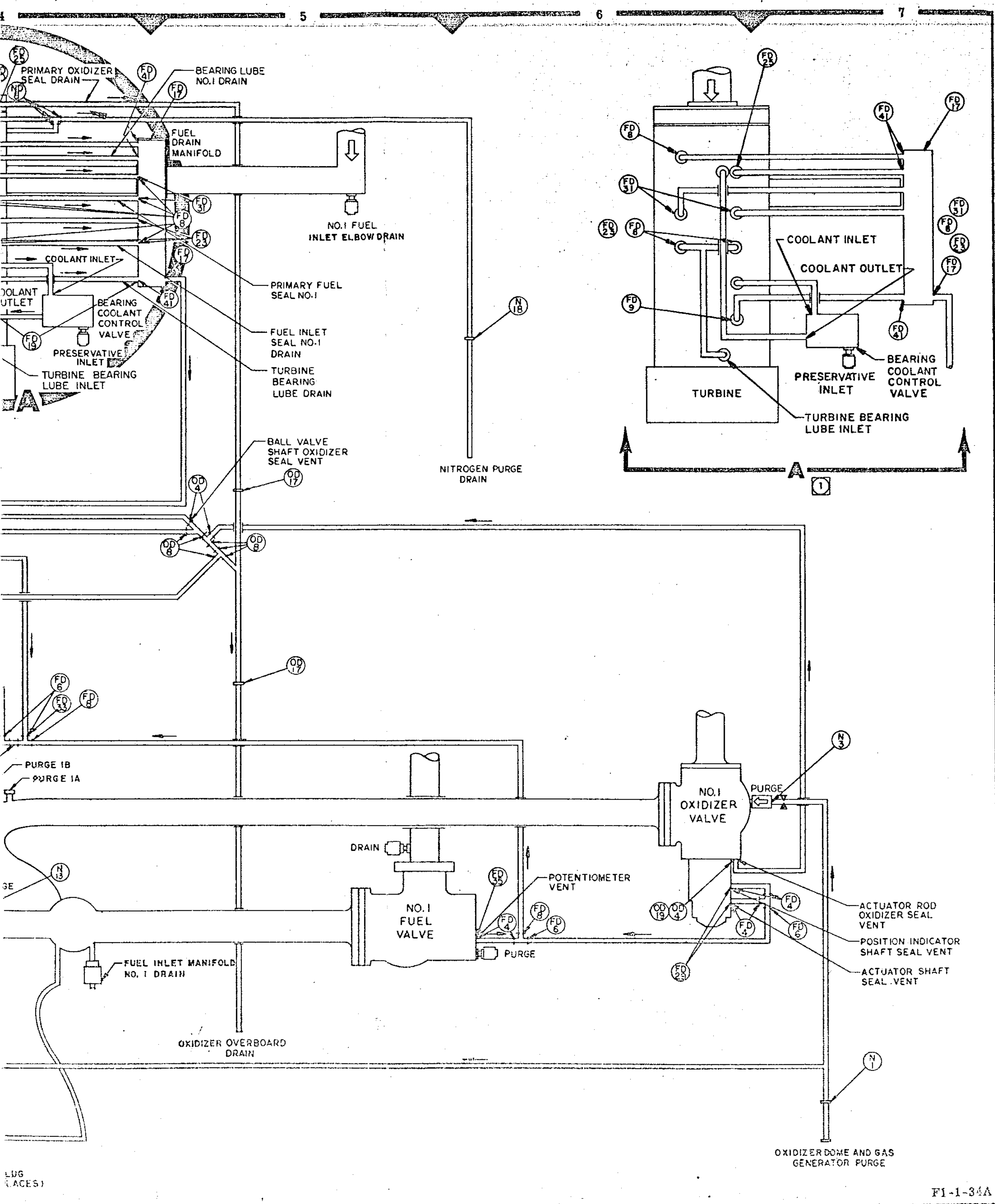


Figure 3-23. Engine Schematic (Pre-Start)



1 ENGINES INCORPORATING MD145 CHANGE

Figure 2-27. Purge and Drain Joint and Seal Schematic (Sheet 1 of 4)



PRIMARY OXIDIZER SEAL DRAIN
BEARING LUBE NO.1 DRAIN
FUEL DRAIN MANIFOLD
NO.1 FUEL INLET ELBOW DRAIN
COOLANT INLET
COOLANT OUTLET
BEARING COOLANT CONTROL VALVE
PRESERVATIVE INLET
TURBINE BEARING LUBE INLET
PRIMARY FUEL SEAL NO.1
FUEL INLET SEAL NO-1 DRAIN
TURBINE BEARING LUBE DRAIN
BALL VALVE SHAFT OXIDIZER SEAL VENT
NITROGEN PURGE DRAIN
TURBINE
A
PURGE 1B
PURGE 1A
NO. 1 OXIDIZER VALVE
PURGE
DRAIN
NO. 1 FUEL VALVE
POTENTIOMETER VENT
ACTUATOR ROD OXIDIZER SEAL VENT
POSITION INDICATOR SHAFT SEAL VENT
ACTUATOR SHAFT SEAL VENT
FUEL INLET MANIFOLD NO. 1 DRAIN
OXIDIZER OVERBOARD DRAIN
OXIDIZER DOME AND GAS GENERATOR PURGE

F1-1-34A

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature °F	Number of Fasteners
		OXIDIZER PROPELLANT SYSTEM JOINTS						
A4	0-1M	LOX Suction Duct to LOX Pump	NA	TS	17.026	115	-300	36
A4	0-2M	No. 1 and 2 LOX Pump Discharge to Spacer to LOX High-Pressure Ducts (4 seals)	NA	TS	9.00	1,700	-300	24
E1 E6	0-3M	No. 1 and 2 LOX High-Pressure Duct to Spacer to MLV Inlet (4 seals)	NA	TS	9.00	1,700	-300	24
E1 E6	0-4M	No. 1 and 2 MLV to LOX Dome Inlets (2 seals)	NA	TS	9.00	1,500	-300	24
A3	0-5M	No. 2 LOX High-Pressure Duct to B/S Line (2 seals)	NA	TS	1.924	1,200	-300	8
B3	0-6	B/S Line to GG LOX Supply Line (3 different seals)	NA NA NA	TS TS TS	2.486 1.611 2.111	1,200 1,200 1,200	-300 -300 -300	8 8 8
B3	0-7	GG LOX Supply Line to GG Ball Valve	NA	TS	2.486	1,200	-300	8
F5	0-8M	H.E. LOX Check Valve to LOX Dome	NA	TS	2.00	1,450	-300	8
D5	0-9M	H.E. LOX Check Valve to H.E. LOX Flowmeter	NA	TS	1.635	1,400	-300	8
D5	0-10M	H.E. LOX Flowmeter to H.E. LOX Inlet Line	NA	TS	1.635	1,350	-300	8
C4	0-11	H.E. LOX Bypass Line to H.E. LOX Inlet Line (2 seals)	NA	TS	1.026	1,300	-300	4
C4	0-12M	H.E. LOX Inlet Line to H.E.	NA	TS	3.735	1,300	-300	8
C4	0-13M	H.E. GOX Outlet Line to H.E.	NA	CN	3.780	1,300	800	8

Figure 2-26. System Joint and Seal Schematic (Sheet 2 of 13)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
		OXIDIZER PROPELLANT SYSTEM JOINTS (continued)						
C4	0-14	H.E. LOX Bypass Line to H.E. GOX Outlet Line	NA	TS	1.032	1,300	0	4
C4	0-15	H.E. GOX Outlet Line to H.E. GOX Wrap-Around Line	NA	SN	1.530	1,300	800	8
D5	0-16M	H.E. LOX Inlet Pressure Transducer [a]	NA	TS	0.510	1,300	-300	4
D5	0-17M	H.E. LOX Inlet Temperature Transducer[a]	NA	TS	0.510	1,300	-300	4
D5	0-18	Tube (H.E. LOX Inlet Pressure)[a]	NA	TS	0.510	1,300	-300	4
C4	0-19M	H.E. GOX Out Pressure Transducer and Hose (2 seals)	NA	CN	0.510	1,300	800	4
C4	0-20M	H.E. GOX Out Temperature Transducer[a]	NA	CN	0.510	1,300	800	4
A3 A4	0-21M	LOX Pump Discharge Pressure Transducer and Tube Assembly (4 seals)	NA	TS	0.510	1,700	-300	4
B4	0-23	GG LOX Purge Check Valve to GG Ball Valve	NA	TS	0.464	1,200	-300	3
A4	0-25	LOX Seal Cavity Pressure Transducer[a]	NA	TS	0.510	12	-300 to +130	4
A4	0-26	LOX Pump Seal Cavity; Static Firing Instrumentation (Port PO2b-2)(4 seals)	F	AL	0.213	1,700	-300	1
A3 A4	0-28	LOX Pump Discharge No. 2; Static Firing Instrumentation (Port PO2b-2)(2 seals each of 2 different seals)	KB	TS	0.451	1,700	-300	1
			F	AL	0.213	1,700	-300	1

(a) Engines not incorporating MD96 or MD97 change

Figure 2-26. System Joint and Seal Schematic (Sheet 3 of 13)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
		OXIDIZER PROPELLANT SYSTEM JOINTS (continued)						
A5 (continued)	0-29	LOX Pump Discharge No. 1; Static Firing	KB	TS	0.451	1,700	-300	1
		Instrumentation (Port PC2b-1)(2 seals each of 2 different seals)	F	AL	0.213	1,700	-300	1
F3	0-30	Oxidizer Dome to Injector	SP	STF	41.062	1,450	-300	58
		FUEL PROPELLANT SYSTEM JOINTS						
A2 A5	F-1	Fuel Suction Duct to Fuel Low-Pressure Duct (2 seals)	GO	VA	12	150	0-130	40
A4	F-2M	Fuel Low-Pressure Duct to Fuel Pump Inlet (2 seals)	GO	VA	8.5	150	0-130	36
B4	F-3M	No. 1 and 2 Fuel Pump Outlet to Spacer to High-Pressure Ducts (4 seals)	GO	VA	6	1,815	0-130	20
B3	F-4M	No. 2 Fuel High-Pressure Duct to GG	GO	VA	2.28	1,815	0-130	8
E		Fuel Upstream Line	GO	VA	1.25	1,815	0-130	8
B3	F-5	GG Fuel Upstream Line to GG Fuel Downstream Line	GO	VA	1.25	1,815	0-130	8
B3	F-6	GG Fuel Downstream Line to GG Ball Valve Inlet	GO	VA	2	1,330	0-130	8
E5	F-7	No. 1 Fuel High-Pressure Duct to Igniter Fuel Valve Supply Line	GO	VA	0.875	1,815	0-130	4
		No. 1 Fuel High-Pressure Duct to Igniter Fuel Valve Supply	OR	VA	1.176	1,815	0-130	4
E3	F-8	Igniter Fuel Valve Supply Line to Igniter Fuel Valve Inlet	GO	VA	0.625	1,700	0-130	4
		Igniter Fuel Valve Supply Line to Igniter Fuel Valve Inlet (2 seals)	OR	VA	1.176	1,700	0-130	4

Figure 2-26. System Joint and Seal Schematic (Sheet 4 of 13)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
		FUEL PROPELLANT SYSTEM JOINTS (continued)						
E4	F-9	Igniter Fuel Valve to Igniter Fuel Line	GO	VA	0.625	1,500	0-130	4
F4	F-10	Igniter Fuel Line to Thrust Chamber Injector	GO	VA	0.625	1,400	0-130	4
E5	F-11	No. 1 High-Pressure Duct to Gimbal Supply	GO	VA	3	1,815	0-130	8
		Cover	GO	VA	1.875	1,815	0-130	8
F2	F-12M	Fuel High-Pressure Duct to No. 1 and 2 MFV (2 seals)	GO	VA	6.52	1,815	0-130	20
F5		Fuel High-Pressure Duct to Spacer to No. 1 and 2 MFV (4 seals)	GO	VA	6.52	1,815	0-130	20
G2 G5	F-13M	No. 1 and 2 MFV to Fuel Manifold Inlet (2 seals)	GO	VA	3	1,520	0-130	20
F4	F-14	Prefill Inlet Boss (cover)	GO	VA	1.492	1,520	0-130	6
F5	F-15M	Prefill Level Detector Boss	GO	VA	1.499	1,520	0-130	6
B2	F-16	High-Pressure Duct Bleed Line to Low-Pressure Duct	GO	VA	0.57	1,800	0-130	4
B2	F-17	High-Pressure Duct Bleed Line to High-Pressure Duct	GO	VA	0.735	1,800	0-130	4
A5 B5	F-18[a]	Fuel Pump Inlet Temperature Transducer	GO	VA	0.735	150	0-130	4
B4	F-19	Bearing Jet Pressure Transducer	GO	VA	0.735	400	0-130	4
B3 B4	F-20	Fuel Pump Discharge Pressure Transducer (4 seals)	GO	VA	0.735	1,815	0-130	4
A3 A4	F-21	Fuel Pump Inlet Pressure Transducer (2 seals)	GO	VA	0.735	150	0-130	4
A3 A4	F-22	Fuel Pump Inlet Pressure Adapter to Inlet (2 seals)	GO	VA	0.735	150	0-130	4
G3 G4	F-23	Fuel Inlet Manifold Disconnect (2 seals)	OR	VA	1.045	1,520	0-130	4

(a) Engines not incorporating MD96 or MD97 change

Figure 2-26. System Joint and Seal Schematic (Sheet 5 of 13)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
		FUEL PROPELLANT SYSTEM JOINTS (continued)						
G2 G5	F-24	Fuel Valve Drain Port Disconnect (2 seals)	OR	VA	0.468	1,520	0-130	1
E4	F-25	Igniter Fuel Supply Line Disconnect	OR	VA	0.739	1,815	0-130	4
[illegible]	F-26	Fuel Impeller Back-casing Supply Orifice	GO	VA	1.125	1,815	0-130	4
F2 F5	F-27	Fuel Valve Disconnect (2 seals)	OR	VA	0.739	1,815	0-130	4
E3	F-28	Adapter, Hypergol Bleed	GO	VA	0.401	1,700	0-130	4
E3	F-29	Adapter Plug, Hypergol Bleed	OR	VA	0.351	1,700	0-130	1
F3	F-30	Prefill Inlet Valve Assembly	OR	VA	0.75	1,520	0-130	6
F4	F-31	Calip Switch Boss to Calip Switch	GO	VA	0.735	1,520	0-130	6
B2	F-32	High-Pressure Duct Bleed Line to Low-Pressure Duct	GO	VA	0.735	1,815	0-130	4
A3 A5	F-33	AN814-4C Plug; Fuel Pump Inlet (3 seals)	OR	VA	0.351	150	0-130	1
B4	F-34	Fuel Inlet Duct to Pump; Seal Monitoring Port (2 seals)	OR	VA	0.239	150	0-130	1
B5	F-35	Fuel High-Pressure Duct; Disconnect	OR	VA	0.739	1,815	0-130	4
B3	F-36	Gas Generator Fuel Drain Disconnect	OR	VA	0.468	1,300	0-130	1
		(2 different seals)	OR	VA	0.351	1,300	0-130	1
	F-38	Fuel Pump Inlet No. 2; Static Firing Instrumentation (Port KF6d-2)(5 RD	OR	VA	0.351	150	0-130	1
		and 2 VSF seals)	F	AL	0.213	150	0-130	1
	F-40	No. 2 Fuel Discharge; Static Firing Instrumentation (Port PF2b-2)(2 seals)	F	AL	0.213	150	0-130	1
B4	F-41	Fuel Impeller Back-casing; Static Firing Instrumentation (PF-10)(2 seals)	F	AL	0.213	1,300	0-130	1

Figure 2-26. System Joint and Seal Schematic (Sheet 6 of 13)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
		FUEL PROPELLANT SYSTEM JOINTS (continued)						
A4	F-43	Fuel Pump Discharge No. 1; Static Firing Instrumentation (Port PF2b-1)(2 seals each of 2 different seals)	OR	VA	0.351	1,815	0-130	1
			F	AL	0.213	1,815	0-130	1
B5	F-44	LOX Pump Bearing Jet; Static Firing Instrumentation (Port LD1b)(2 seals)	F	AL	0.213	1,815	0-130	1
	F-45	Fuel Pump Inlet No. 1; Static Firing Instrumentation (Port KF6b-1)(2 seals)	F	AL	0.213	150	0-130	1
		HELIUM SYSTEM JOINTS						
C4	H-1	Customer Connect to Helium Supply Crossover	NA	TS	1.250	350	-300	6
C4	H-2	Helium Crossover to Supply Duct Assembly	NA	TS	1.250	350	-300	6
C4	H-3	Helium Supply Duct to Bypass Hose (2 seals)	NA	TS	1.026	350	-300	4
C4	H-4M	Helium Supply Duct to H.E.	NA	CN	3.2	350	-300	8
C4	H-5M	H.E. to Helium Return Duct	NA	CN	3.2	250	600	8
C4	H-6	Helium Return Duct to Bypass Hose	NA	TS	1.032	250	0	4
C4	H-7	Helium Return Duct to Crossover	NA	SN	1.530	250	600	8
C4	H-8	Helium Crossover Return to Customer Connect	NA	SN	1.530	250	600	8
C4	H-9M[a]	H.E. Helium Outlet Pressure Transducer	NA	CN	0.510	250	600	4
C4	H-10M[a]	H.E. Helium Outlet Temperature Transducer	NA	CN	0.510	250	600	4

(a) Engines not incorporating MD96 or MD97 change

Figure 2-26. System Joint and Seal Schematic (Sheet 7 of 13)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
HELIUM SYSTEM JOINTS (continued)								
C4	H-11M[a]	H.E. Helium Inlet Pressure Transducer	NA	TS	0.510	350	-300	4
C4	H-12[a]	H.E. Helium Inlet Temperature Transducer	NA	TS	0.510	350	-300	4
C4	H-13[a]	703203 Hose (H.E. Helium Inlet Pressure)	NA	TS	0.510	350	-300	4
C4	H-14[a]	703203 Hose (H.E. Helium Outlet Pressure)	NA	CN	0.510	250	600	4
HYDRAULIC FLUID SYSTEM JOINTS								
D3	HF-2	Hydraulic Supply Crossover Cover	GO	VA	1.31	1,800	0-130	8
D3	HF-3	Hydraulic Supply Crossover Line	GO	VA	0.875	1,800	0-130	8
C4	HF-4	Ground Supply Port of Control Valve	GO	VA	0.875	1,800	0-130	4
D2	HF-5	High-Pressure Duct to Control Valve Supply Line (2 seals)	GO	VA	1.176	1,800	0-130	4
C3	HF-6	Engine Supply Port of Control Valve (2 seals)	OR	VA	1.114	1,800	0-130	4
C3	HF-7	Close-Pressure Port of Control Valve (2 seals)(1 seal)	GO	VA	0.875	1,800	0-130	4
C3	HF-8	Open-Pressure Port of Control Valve (2 seals)	GO	VA	0.875	1,800	0-130	4
F1 F6	HF-9	No. 1 and 2 MLV Open Control Port (2 seals)	GO	VA	0.870	1,800	0-130	4
G1 G6	HF-10	No. 1 and 2 MLV Close Control Port (2 seals)	GO	VA	0.625	1,800	0-130	4
G1 G6	HF-11	No. 1 and 2 Main Oxidizer Sequence Valve Inlet (2 seals)	GO	VA	0.406	1,800	0-130	4

(a) Engines not incorporating MD96 or MD97 change

Figure 2-26. System Joint and Seal Schematic (Sheet 8 of 13)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
		HYDRAULIC FLUID SYSTEM JOINTS (continued)						
G1 G7	HF-12	No. 1 and 2 Main Oxidizer Sequence Valve Outlet (2 seals)	GO	VA	0.406	1,800	0-130	4
D3	HF-13	IMV Hydraulic Inlet Port	GO	VA	0.625	1,800	0-130	4
D3	HF-14	IMV Open Port to No. 1 MFV	GO	VA	0.406	1,800	0-130	4
D3	HF-15	IMV Open Port to No. 2 MFV	GO	VA	0.406	1,800	0-130	4
D3	HF-16	IMV Hydraulic Return Port	GO	VA	0.500	1,800	0-130	4
B1	HF-17	IMV Return to Common System Return	GO	VA	0.500	1,800	0-130	4
C2	HF-18	Control Valve Hydraulic Return Port	GO	VA	1.125	1,800	0-130	6
B2	HF-19	Control Valve Return Line to Common Return	GO	VA	1.125	1,800	0-130	6
A2	HF-20	Blind Cover 601546 to Common Hydraulic Return	GO	VA	2.448	1,800	0-130	8
B2	HF-21	Engine Hydraulic Return Line at Checkout Valve	GO	VA	2.750	1,800	0-130	8
A2	HF-22	Engine Hydraulic Return Line to No. 2 Fuel Inlet	GO	VA	2.750	1,800	0-130	8
B2	HF-23	Actuator Return Line Assembly to Checkout Valve	GO	VA	2.750	1,800	0-130	8
F2 F6	HF-24	No. 1 and 2 MFV Open Control Port (2 seals)	GO	VA	0.735	1,800	0-130	8
F2 F6	HF-25	No. 1 and 2 MFV Closing Control Port (2 seals)	GO	VA	0.406	1,800	0-130	4
C3	HF-26	Flange in GG Close Line	GO	VA	0.406	1,800	0-130	4
B3	HF-27	Closing Control Line at GG	GO	VA	0.406	1,800	0-130	4
B3	HF-28	Opening Control Line at GG	GO	VA	0.400	1,800	0-130	6
F3	HF-29	IMV Sense Line at Fuel Manifold	GO	VA	0.307	1,800	0-130	4

Figure 2-26. System Joint and Seal Schematic (Sheet 9 of 13)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
		HYDRAULIC FLUID SYSTEM JOINTS (continued)						
D3	HF-32	IMV Sense Pressure Inlet Port (2 seals)	OR	VA	0.739	1,800	0-130	4
B2	HF-35	Common Hydraulic Return Pressure Transducer	GO	VA	0.735	1,800	0-130	4
C3	HF-36(a)	Engine Control Open Transducer	GO	VA	0.735	1,800	0-130	4
C3	HF-37(a)	Engine Control Close Transducer	GO	VA	0.735	1,800	0-130	4
C3	HF-38	Plugs at Open and Close Control Ports of Control Valve (2 seals)	OR	VA	0.351	1,800	0-130	1
A2	HF-39	Hydraulic Return Disconnect	OR	VA	0.739	1,800	0-130	4
D2	HF-40	Four-Way Valve Supply Disconnect	OR	VA	0.739	1,800	0-130	4
B2	HF-41	Checkout Valve to Hydraulic Return Ground Facility Line	GO	VA	2.323	1,800	0-130	8
B1	HF-44	Gimbal Return Line Cover	GO	VA	2.448	1,800	0-130	8
B1	HF-45	Gimbal Return Line Cover Disconnect	OR	VA	0.739	1,800	0-130	4
C1	HF-46	Hydraulic Return Line to Crossover	GO	VA	1.52	1,800	0-130	6
C2	HF-47	Control System Supply; Static Firing Instrumentation (Port NH1b)(2 seals each of 2 different seals)	OR F	VA AL	0.351 0.213	1,800 1,800	0-130 0-130	1 1
C3	HF-48	Engine Control Open; Static Firing Instrumentation (Port NH3b) (2 seals)	OR	VA	0.351	1,800	0-130	1

(a) Engines not incorporating MD96 or MD97 change

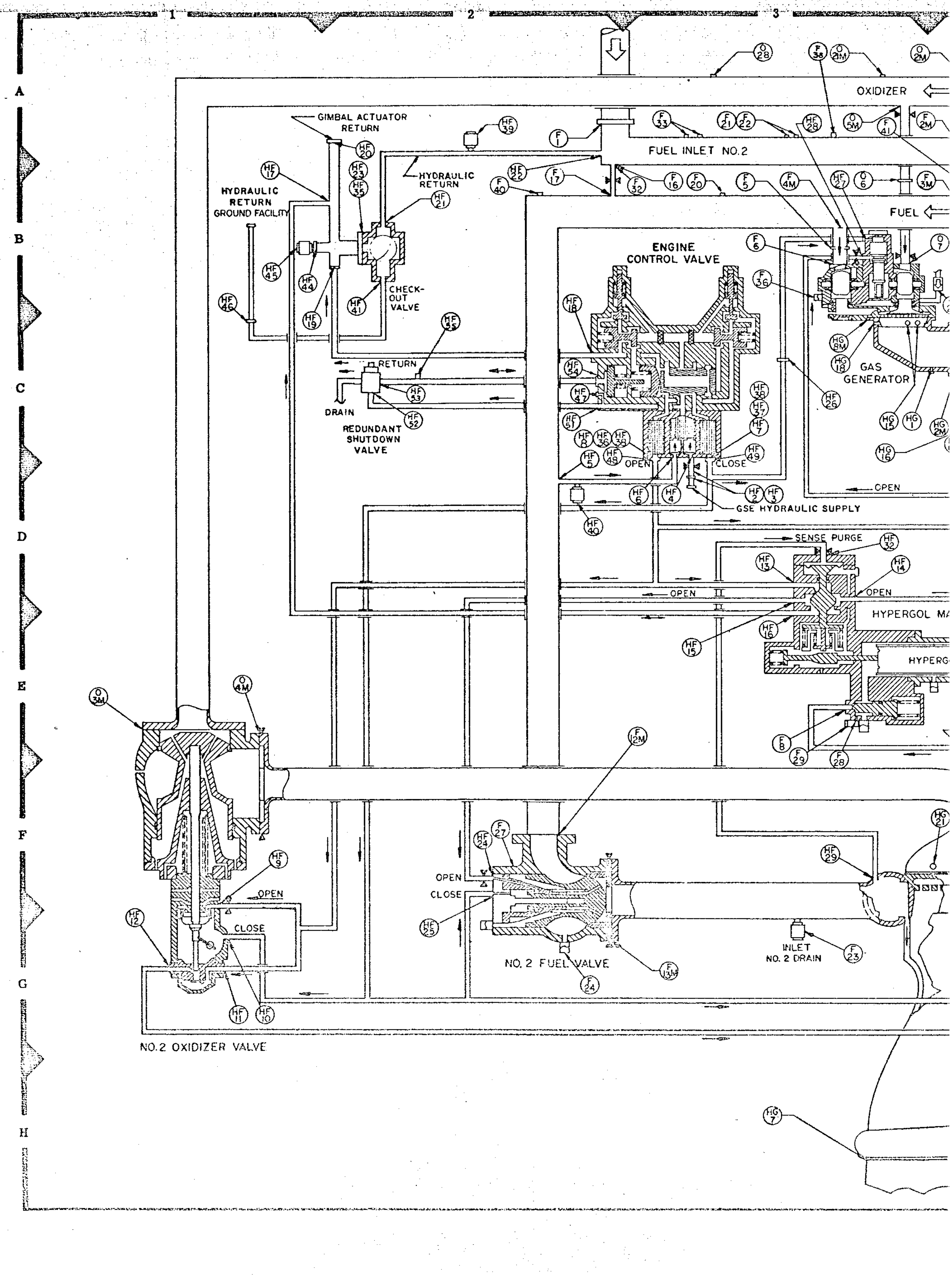
Figure 2-26. System Joint and Seal Schematic (Sheet 10 of 13)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
		HYDRAULIC FLUID SYSTEM JOINTS (continued)						
C3	HF-49	Engine Control Close; Static Firing Instrumentation (Port NH2b) (2 seals each of 2 different seals)	OR	VA	0.351	1,800	0-130	1
			F	AL	0.213	1,800	0-130	1
C2	HF-51	Engine Control Valve to Redundant Shutdown Valve (Port NH1a)	F	AL	0.213	1,800	0-130	1
			O	VA	0.351	1,800	0-130	1
C2	HF-52	Engine Control Valve to Redundant Shutdown Valve (In Port)	GO	VA	0.182	1,800	0-130	4
C2	HF-53	Redundant Shutdown Valve to Engine Control Valve (Out Port)	GO	VA	0.182	1,800	0-130	4
C2	HF-54	Redundant Shutdown Valve to Engine Control Valve (Override Port)	F	AL	0.213	1,800	0-130	1
			O	VA	0.644	1,800	0-130	1
C2	HF-55	Redundant Shutdown Valve to Engine Control Valve (Port NH8) (2 seals each of 2 different seals)	OR	VA	0.351	1,800	0-130	1
			F	AL	0.213	1,800	0-130	1
		HOT-GAS SYSTEM JOINTS						
C4	HG-1	Gas Generator Combustor Drain Plug	KB	GS	0.451	1,000	1,450	1
C4	HG-2M	Gas Generator Combustor to Turbine Inlet	NA	SN	8.780	1,000	1,450	24
B4	HG-3	Turbine Torus Temperature Transducer	NA	SN	0.510	950	1,600	4
C4	HG-4M	Turbine to Heat Exchanger	NA	SN	40.755	60	1,170	120
C4	HG-5M	Turbine Outlet Pressure Transducer and Hose (2 seals)	NA	SN	0.510	60	1,170	4

Figure 2-26. System Joint and Seal Schematic (Sheet 11 of 13)

Joint Information			Seal Information			Environment		
Zone	Code	Description	Type	Material	ID, in.	Pressure, psig	Temperature, °F	Number of Fasteners
		HOT-GAS SYSTEM JOINTS (continued)						
C4	HG-6M	Heat Exchanger to Exhaust Manifold	NA	SN	23.94	30	1,170	60
H3	HG-7	Thrust Chamber to Nozzle Extension	TP	AN	(117.1 in length per seal)	20	1,170	240
C4	HG-8M	GG Chamber Pressure Transducer	NA	SN	0.510	1,000	140	4
F4	HG-9M	Thrust Chamber Combustion Chamber Pressure Transducer	NA	SN	0.510	1,100	500	4
F4	HG-10	Thrust Chamber Pressure Transducer Boss	NA	CN	0.875	1,100	500	6
F4	HG-11	Thrust Chamber Pressure Adapter Plug	KB	GS	0.325	1,100	500	1
H4	HG-13	Nozzle Extension Igniter (2 seals)	CR	C	0.682	20	1,170	1
C4	HG-15	Gas Generator Igniter (2 seals)	CR	C	0.682	1,000	1,450	1
C4	HG-16	Heat Exchanger; Static Firing Instrumentation	KB	TS	0.451	1,000	1,450	1
		(Port TG5A) (2 seals each of 2 different seals)	F	AL	0.213	1,000	1,450	1
C4	HG-18	GG Chamber; Static Firing Instrumentation	KB	TS	0.451	1,000	140	1
		(Port GG1b) (1 K-seal and 2 VSF seal)	F	AL	0.213	1,000	140	1

Figure 2-26. System Joint and Seal Schematic (Sheet 12 of 13)



1
2
3
A
B
C
D
E
F
G
H
OXIDIZER
FUEL INLET NO.2
FUEL
GIMBAL ACTUATOR
RETURN
HYDRAULIC
RETURN
HYDRAULIC
RETURN
GROUND FACILITY
CHECK-
OUT
VALVE
ENGINE
CONTROL VALVE
GAS
GENERATOR
RETURN
DRAIN
REDUNDANT
SHUTDOWN
VALVE
OPEN
CLOSE
GSE HYDRAULIC SUPPLY
SENSE PURGE
OPEN
OPEN
HYPERGOL MA
HYPERG
OPEN
CLOSE
NO. 2 FUEL VALVE
INLET
NO. 2 DRAIN
OPEN
CLOSE
NO.2 OXIDIZER VALVE

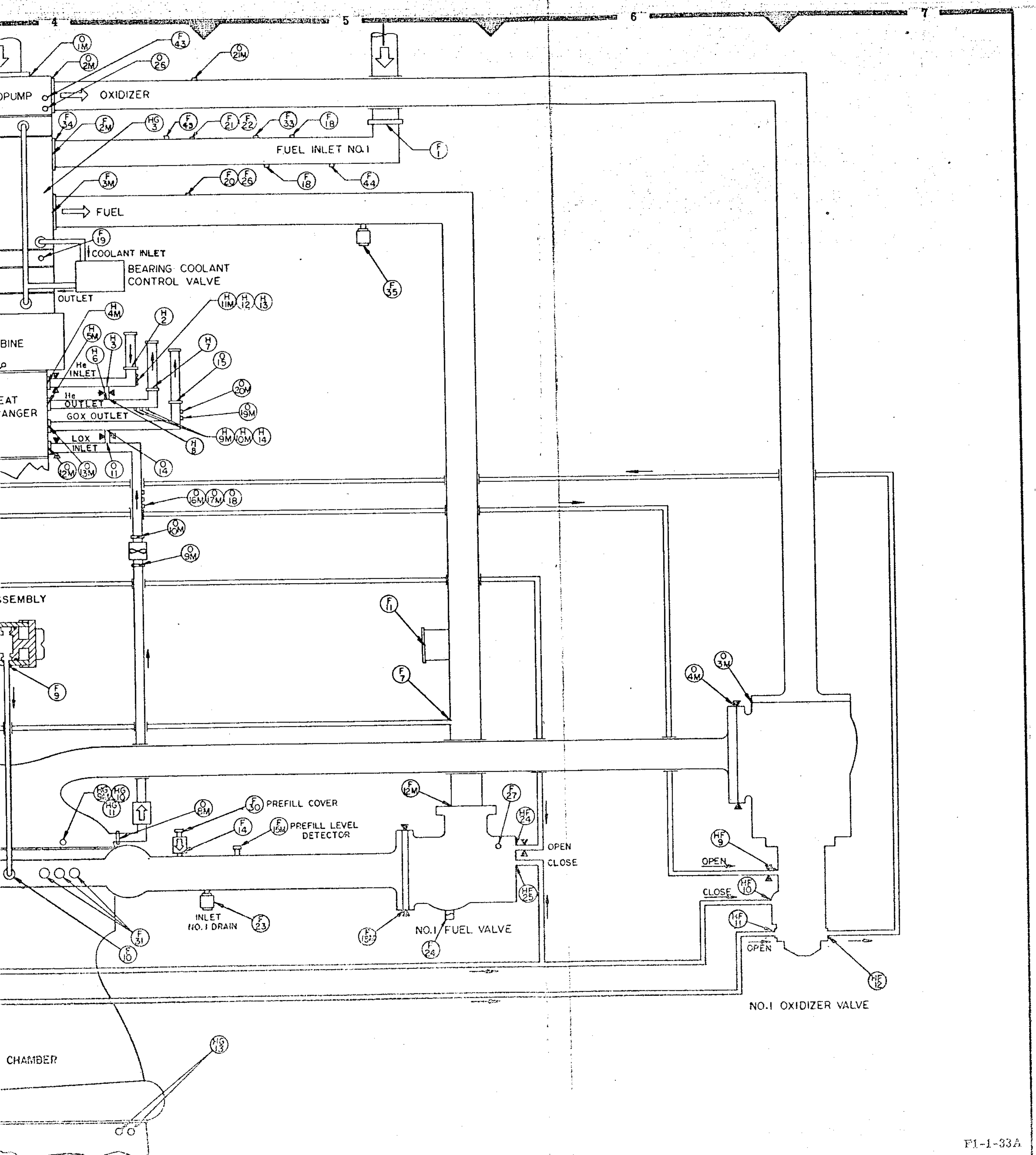


Figure 2-26. System Joint and Seal Schematic (Sheet 1 of 13)

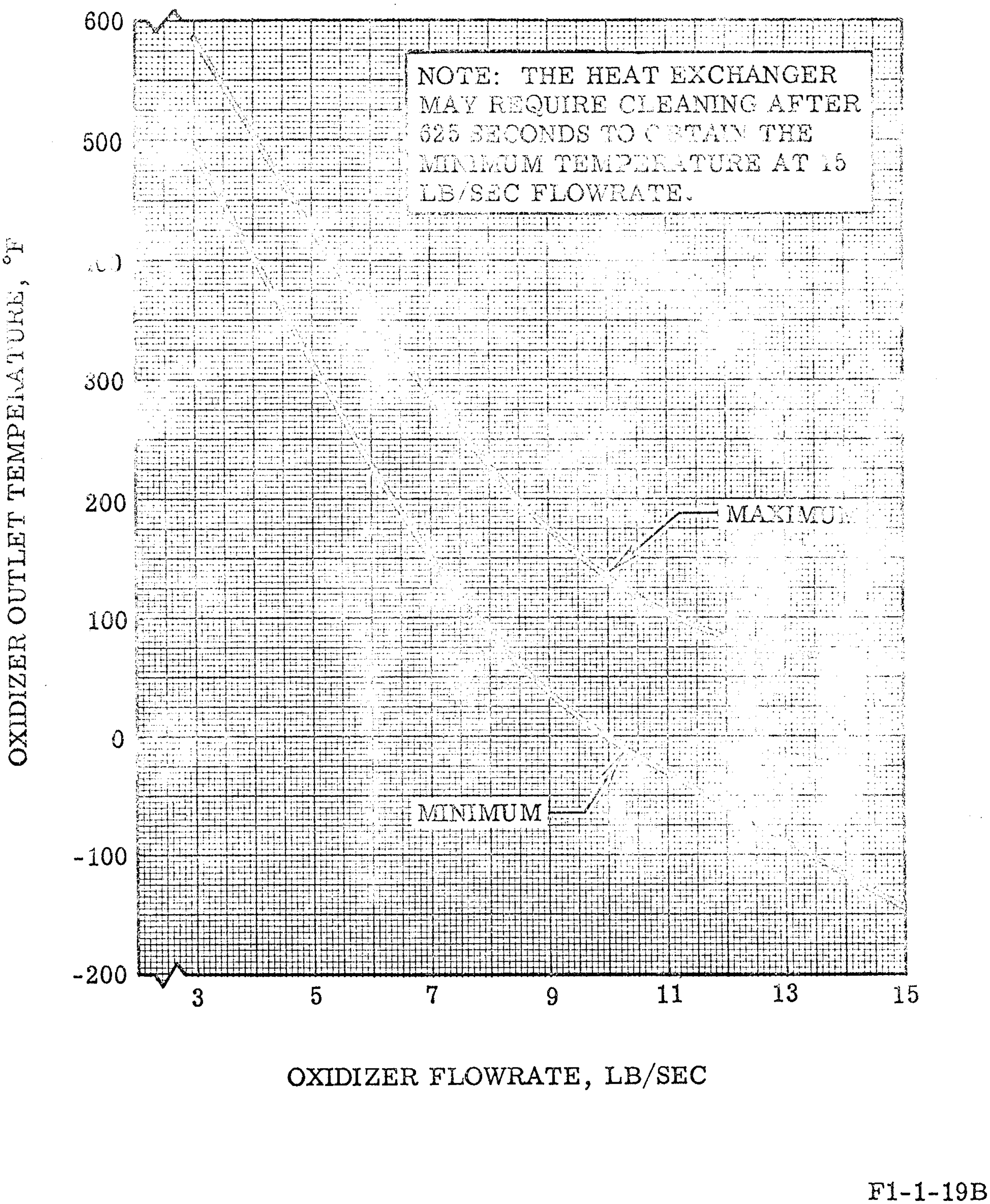


Figure 2-9L. Estimated Oxidizer Outlet Temperature Versus Oxidizer Flowrate for Steady-State Operation of Heat Exchanger

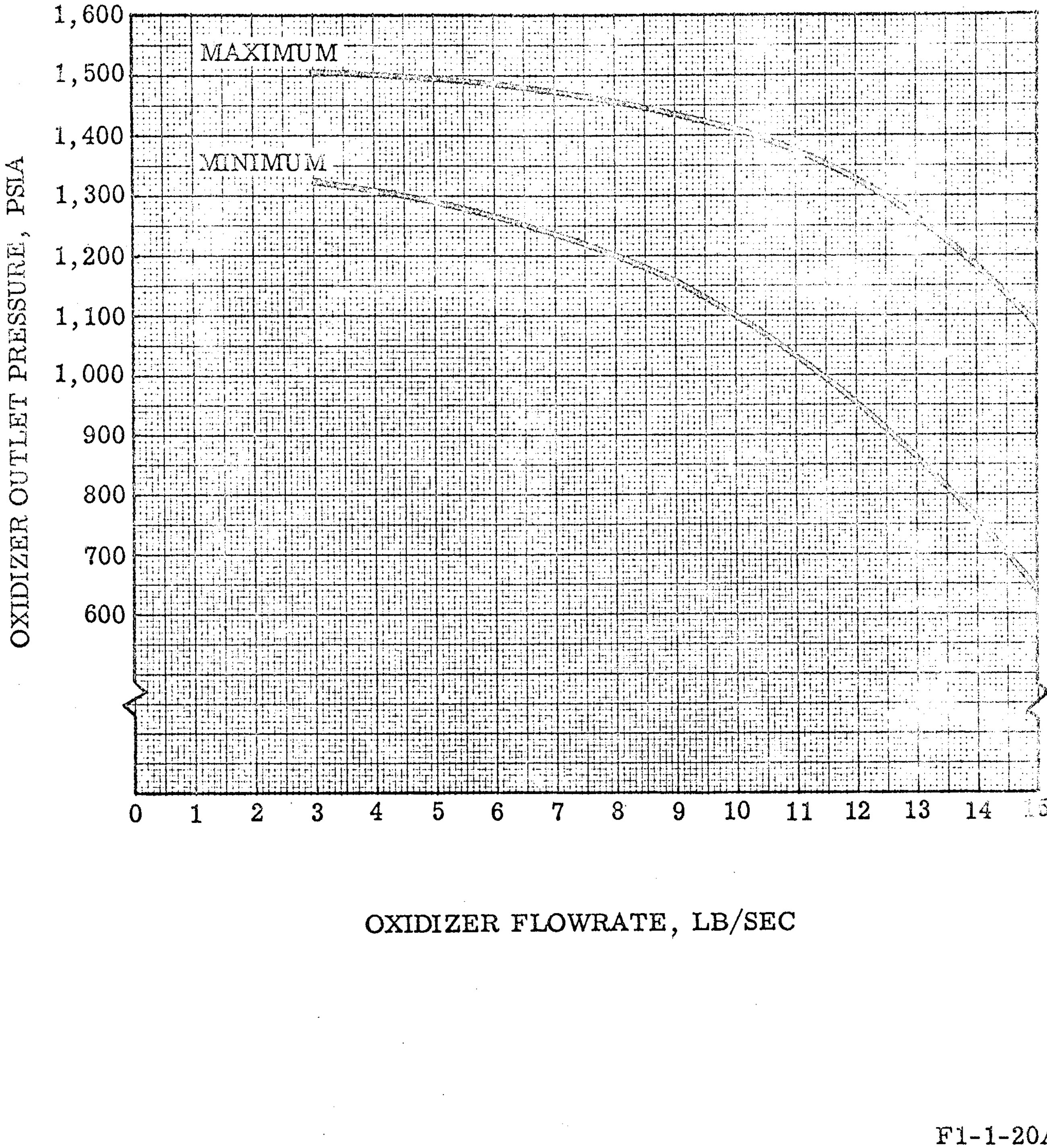


Figure 2-9M. Estimated Oxidizer Outlet Pressure Versus Oxidizer Flowrate for Steady-State Operation of Heat Exchanger

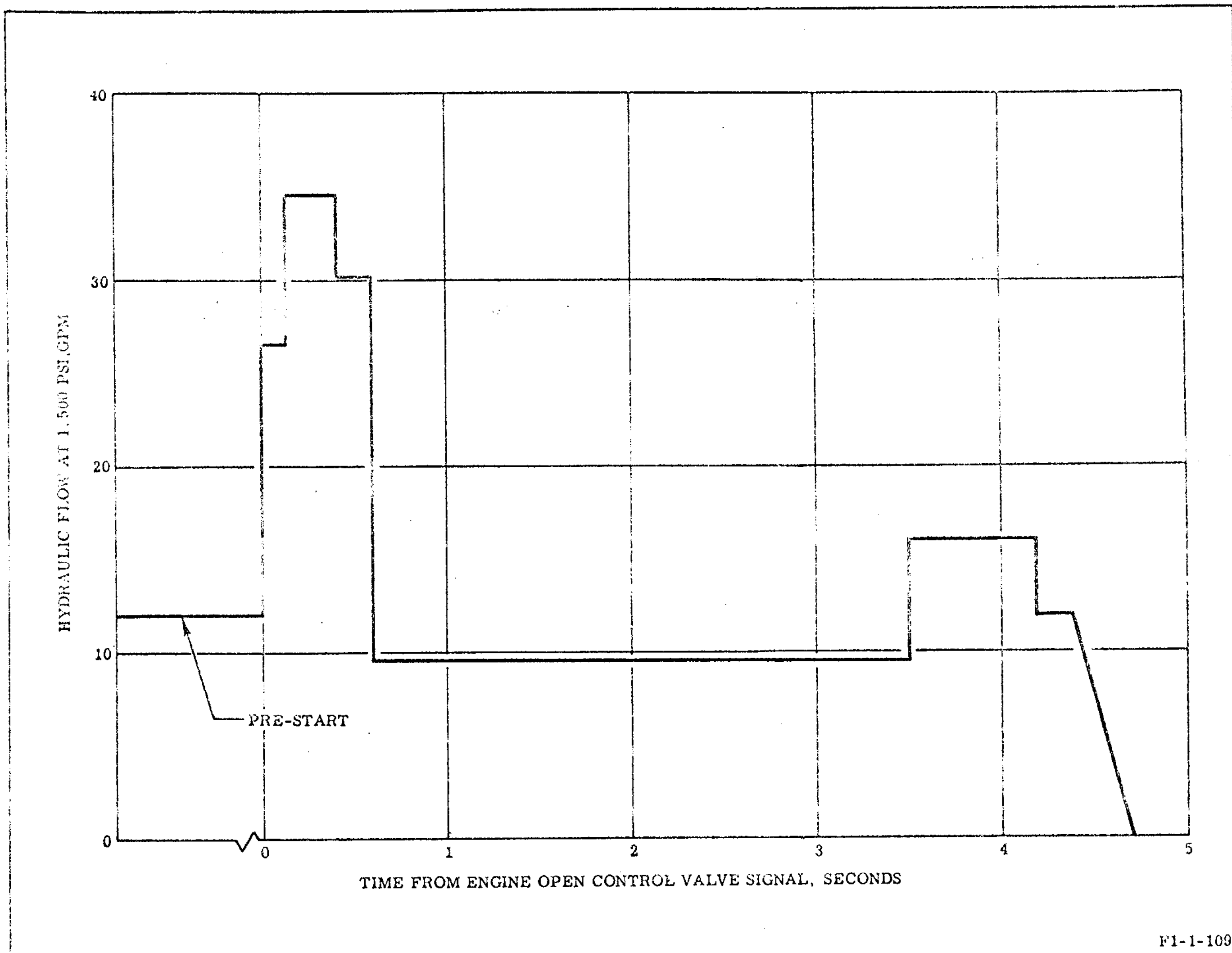


Figure 2-10. Hydraulic Flowrate at Nominal Control System Values

2-25. The engine without thermal insulation installed, when supplied with required operating fluids, electrical power, and fuel and oxidizer propellants, will not suffer detrimental effects when exposed to an ambient temperature range of 0° to 130° F for 16 hours, except as limited by the freezing point of the thrust chamber prefill fluid.

2-26. The engine with thermal insulation installed, when supplied with required operating fluids, electrical power, and fuel and oxidizer propellants, will not suffer detrimental effects when exposed to an ambient temperature range of 28° to 130° F for 16 hours, except as limited by the freezing point of the thrust chamber prefill fluid.

2-27. GROUND HYDRAULIC FLUID SUPPLY TEMPERATURE.

2-28. Ground hydraulic fluid supplied to the engine must be within a temperature range of 60° to 130° F and a pressure range of 1,400-1,800 psig at the customer connect point whenever oxidizer propellant is in the engine.

2-29. THERMAL INSULATION COCOON ENVIRONMENTAL CONDITIONING ENVELOPE.

2-30. The recommended thermal insulation cocoon environmental conditioning external input to maintain a safe engine starting temperature within the cocoon is presented in figure 2-11. The heated purge supply should be turned on any time the ambient air temperature is 55° F or less with oxidizer propellant in the engine. GN_2 supplied to the engine interface at temperatures and pressures of figure 2-11 and the above conditions will maintain the temperature inside the cocoon, as measured on the Environmental Flight Transducer, at 10° F or above when the outside ambient air temperature is 28° F or above.

2-31. MASS PROPERTIES DATA.

2-32. Weight, center of gravity, and inertia data is presented in figures 2-12 through 2-20A to aid in determination of stage-actuator-engine system combined natural frequency and also to aid in trajectory analysis.

2-33. WEIGHT STATUS.

2-34. See figure 2-12 for the approximate weights of the engine major components and figure 2-13 for the current engine weight status.

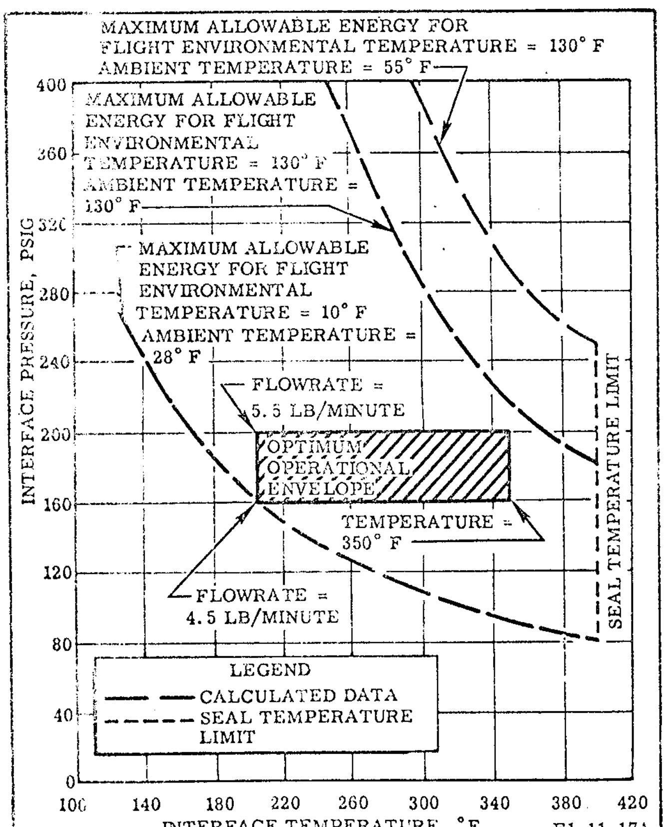


Figure 2-11. Recommended Thermal Insulation Cocoon Purge Operating Range Envelope

COMPONENT	Weight (Pounds)
Gas Generator Assembly (Including combustor, injector, and ball valve)	218
Heat Exchanger	823
Thrust Chamber	
Oxidizer Dome	1,573
Injector	1,171
Thrust Chamber Body	5,237
Extension Nozzle	1,621
Gimbal Bearing	426
Oxidizer System	
Oxidizer Valve	138
No. 1 Turbopump Oxidizer Outlet Line	96
No. 2 Turbopump Oxidizer Outlet Line	70
Fuel System	
Fuel Valve	90
No. 1 Turbopump Fuel Outlet Line	85
No. 2 Turbopump Fuel Outlet Line	68
Adapter (Inlet to pump)	81
Turbopump (Average)	3,150
Hypergol Assembly (Including container, cartridge, mount, and ignition monitor valve)	40
Hydraulic Filter and Four-Way Solenoid Valve Manifold	39
Interface Panel (Without connectors)	413

Figure 2-12. Major Component Weight List

Item	DESCRIPTION	Weight (Pounds) F-2029 Thru F-2042	F-2043 Thru F-2065	F-2066 Thru F-2089	F-2045-1, F-2090 and Subs
1 + 2	Rocket Engine--Wet	20,850	20,746	20,766	20,833
1 + 3	Rocket Engine--Burnout	20,431	20,327	20,347	20,415
1	Rocket Engine--Dry	18,682	18,578	18,598	18,616
	Thrust Chamber (Including skirt, 1,621 lb)	8,508	8,508	8,508	8,511
	Gimbal Bearing	467	467	467	467
	Turbopump	3,152	3,150	3,151	3,149
	Turbopump Mount (Including provisions on T/C, 286 lb)	342	342	342	342
	Oxidizer System	651	651	651	653
	Fuel System	646	646	642	642
	Purge System	39	39	39	39
	Electrical System	83	83	85	85
	Gimbal Supply System	180	180	181	181
	Gas Generator System	336	336	336	336
	Exhaust System (Including T/C exhaust manifold, 826 lb)	995	995	997	998
	Flight Instrumentation	249	146	146	146
	Ignition System	52	52	52	52
	Interface Installation	536	536	543	543
	Pressurization System (Including heat exchanger, 823 lb)	1,022	1,019	1,019	1,029
	Hydraulic Control System	166	167	195	195
	Thermal Insulation--Permanent	58	58	72(a)	72
	Thermal Insulation Set (TIS)	1,200	1,200	1,186	1,186
2	Rocket Engine Fluids (System Full)	2,168	2,168	2,168	2,217
3	Rocket Engine Fluids (Burnout)	1,749	1,749	1,749	1,799

(a) Effective on engines F-2079 and subsequent.

Figure 2-13. Engine Weight Status

2-35. ENGINE COORDINATE AXES.

2-36. See figure 2-14 for engine coordinate axes.

2-37. CENTER OF GRAVITY AND INERTIA DATA.

2-38. See figures 2-18 through 2-20A for the current engine weight, center of gravity, and inertia data.

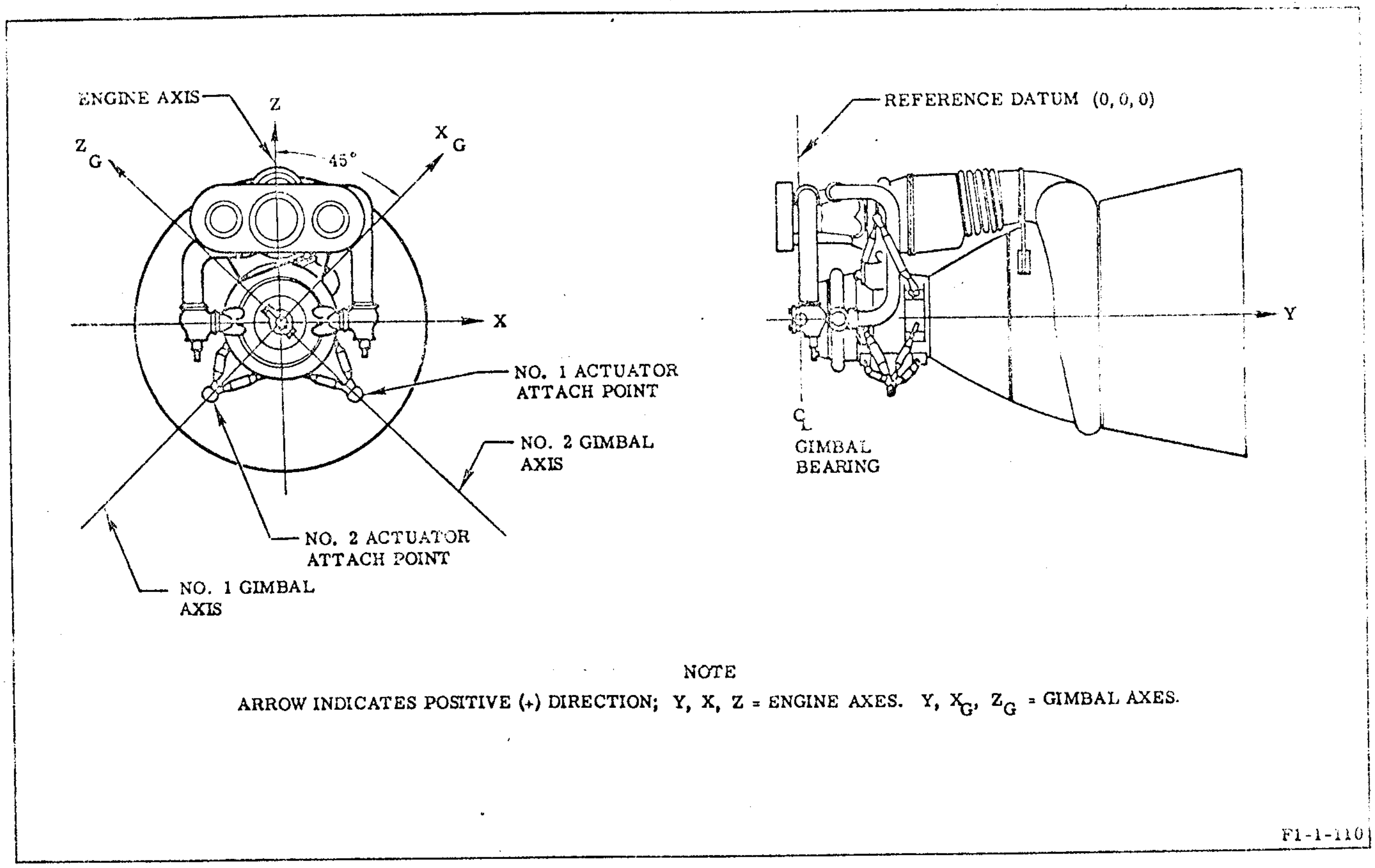


Figure 2-14. Coordinate Axis Diagram

Figures 2-15 through 2-17 deleted.

Item	Description	Weight (Lb)	Center of Gravity (Inches)			Axis System Orientation	Origin of Axes (Inches)			Moment of Inertia (Slug Ft^2)		
			$\overline{Y}$ (+)	$\overline{X}$ (+)	$\overline{Z}$ (+)		Y (+)	X (+)	Z (+)	I_y	I_x	I_z
(1)	Rocket Engine--Dry	18,682	56.2	11.8	11.9	Gimbal	56.2	11.8	11.9	6,822	17,497	17,532
(2)	Rocket Engine--Wet	20,851	54.3	12.1	12.1	Gimbal	54.3	12.1	12.1	7,558	18,841	18,935
(3)[a]	Wet Gimbaled Mass	20,637	54.9	12.3	12.2	Gimbal	54.9	12.3	12.2	7,547	18,687	18,772

(a) Product of Inertia (Slug Ft^2): I_{xz} = +886, I_{yz} = -913, I_{xy} = -966

Figure 2-18. Weight, Center of Gravity, Moment of Inertia, and Product of Inertia Data (Engines F-2029 Through F-2042)

Item	Description	Weight (Lb)	Center of Gravity (Inches) $\overline{Y}$ (+)	$\overline{X}$ (+)	$\overline{Z}$ (+)	Axis System Orientation	Origin of Axes (Inches) Y (+)	X (+)	Z (+)	Moment of Inertia (Slug Ft^2) I_y	I_x	I_z
(1)	Rocket Engine--Dry	18,578	56.3	11.8	11.8	Gimbal	56.3	11.8	11.8	6,790	17,448	17,499
(2)	Rocket Engine--Wet	20,746	54.4	12.1	11.9	Gimbal	54.4	12.1	11.9	7,529	18,795	18,901
(3)[a]	Wet Gimbaled Mass	20,533	55.0	12.3	12.1	Gimbal	55.0	12.3	12.1	7,636	18,800	18,895

(a) Product of inertia (slug ft^2): I_{xz} = +880, I_{yz} = -893, I_{xy} = -961

Figure 2-19. Weight, Center of Gravity, Moment of Inertia, and Product of Inertia Data (Engines F-2043 Through F-2065)

Item	Description	Weight (Lb)	Center of Gravity (Inches) $\overline{Y}$ (+)	$\overline{X}$ (+)	$\overline{Z}$ (+)	Axis System Orientation	Origin of Axes (Inches) Y (+)	X (+)	Z (+)	Moment of Inertia (Slug Ft^2) I_y	I_x	I_z
(1)	Rocket Engine--Dry	18,598	56.3	11.6	11.7	Gimbal	56.3	11.6	11.7	6,809	17,437	17,470
(2)	Rocket Engine--Wet	20,766	54.4	12.0	11.9	Gimbal	54.4	12.0	11.9	7,548	18,779	18,866
(3)[a]	Wet Gimbaled Mass	20,553	55.0	12.1	12.0	Gimbal	55.0	12.1	12.0	7,534	18,625	18,712

(a) Product of inertia (slug ft^2): I_{xz} = +894, I_{yz} = -956, I_{xy} = -1,033

Figure 2-20. Weight, Center of Gravity, Moment of Inertia, and Product of Inertia Data (Engines F-2066 Through F-2089)

Item	Description	Weight (Lb)	Center of Gravity (Inches) Y (+)	X (+)	Z (+)	Axis System Orientation	Origin of Axes (Inches) Y (+)	X (+)	Z (+)	Moment of Inertia (Slug Ft^2) I_y	I_x	I_z
(1)	Rocket Engine--Dry	18,616	56.4	11.6	11.7	Gimbal	56.4	11.6	11.7	6,830	17,537	17,577
(2)	Rocket Engine--Wet	20,833	54.5	12.0	11.9	Gimbal	54.4	12.0	11.9	7,583	18,895	18,984
(3)[a]	Wet Gimbaled Mass	20,620	55.1	12.1	12.0	Gimbal	55.1	12.1	12.0	7,569	18,741	18,830

(a) Product of inertia (slug ft^2): I_{xz} = +899, I_{yz} = -967, I_{xy} = -1,046

Figure 2-20A. Weight, Center of Gravity, Moment of Inertia, and Product of Inertia Data (Engines F-2045-1 and F-2090 Through F-2098)

2-39. INTERFACE CONNECTIONS.

2-40. Interface connections shown contain only physical descriptions of the interface connect points, engine envelope, and engine instrumentation tap locations. For detail design criteria, refer to F-1 Engine Interface Document, R-6749.

2-41. INTERFACE CONNECT POINTS.

2-42. See figure 2-21 for location on engine of stage interface connect points and for engine servicing connect points.

2-43. ENVELOPE DIMENSIONS.

2-44. See figure 2-22 for engine envelope dimensions.

2-45. ELECTRICAL INTERFACE.

2-46. See figure 2-23 for the connector numbers, connector types, pin functions, and other characteristics concerned with electrical interface requirements. An explanation of the terminology used is as follows:

Pin . . . . The pin letter assigned is for both halves of the interface and was derived from the letters on the connector. Signals have been referenced to specific pins.

Functional Description . The purpose and need for the signal in relation to the circuit involved.

Origin . . . . The source of the signal.

Termination . . . . The terminating or receiving point of the signal.

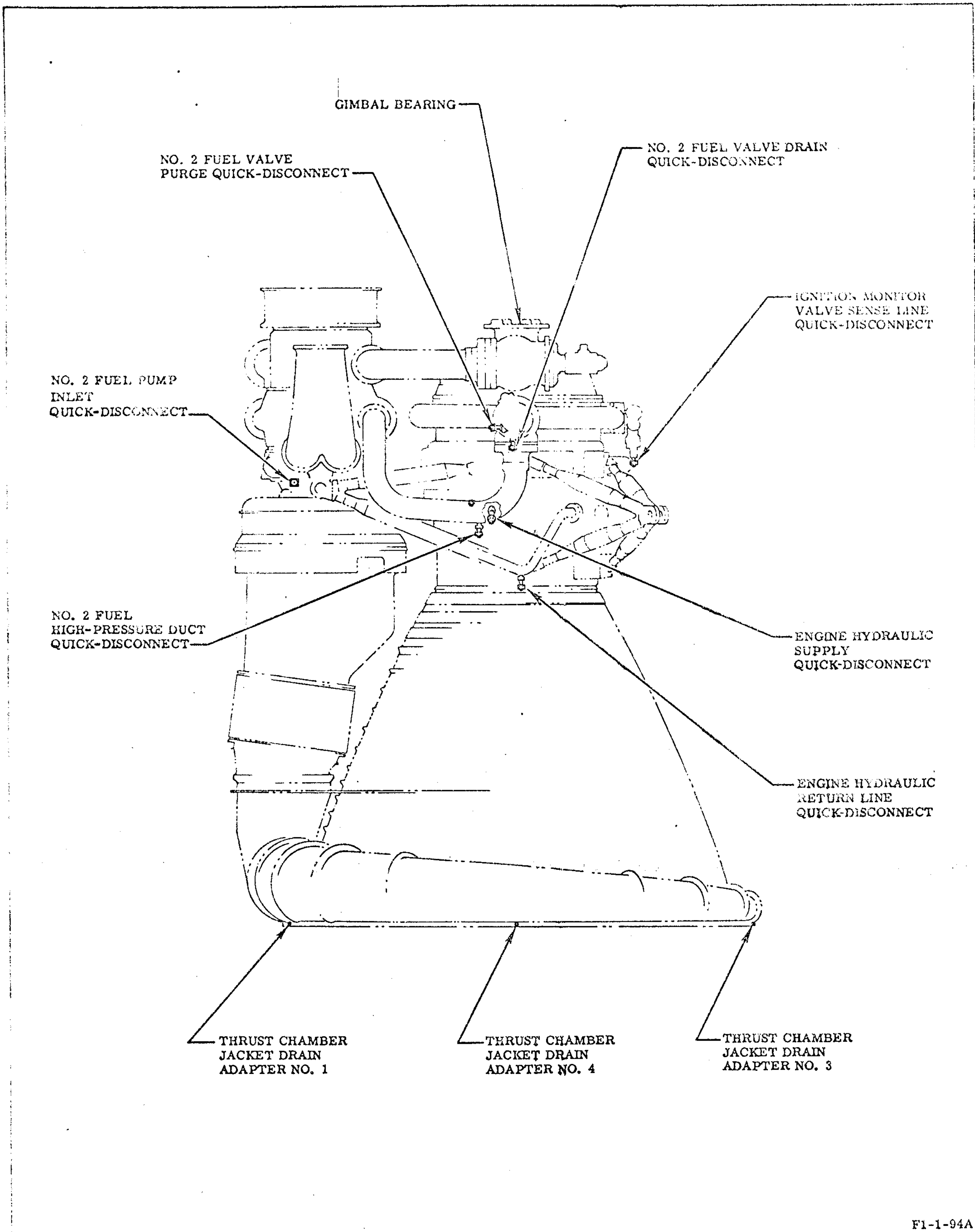


Figure 2-21. Operating and Servicing Interface Connections (Sheet 1 of 3)

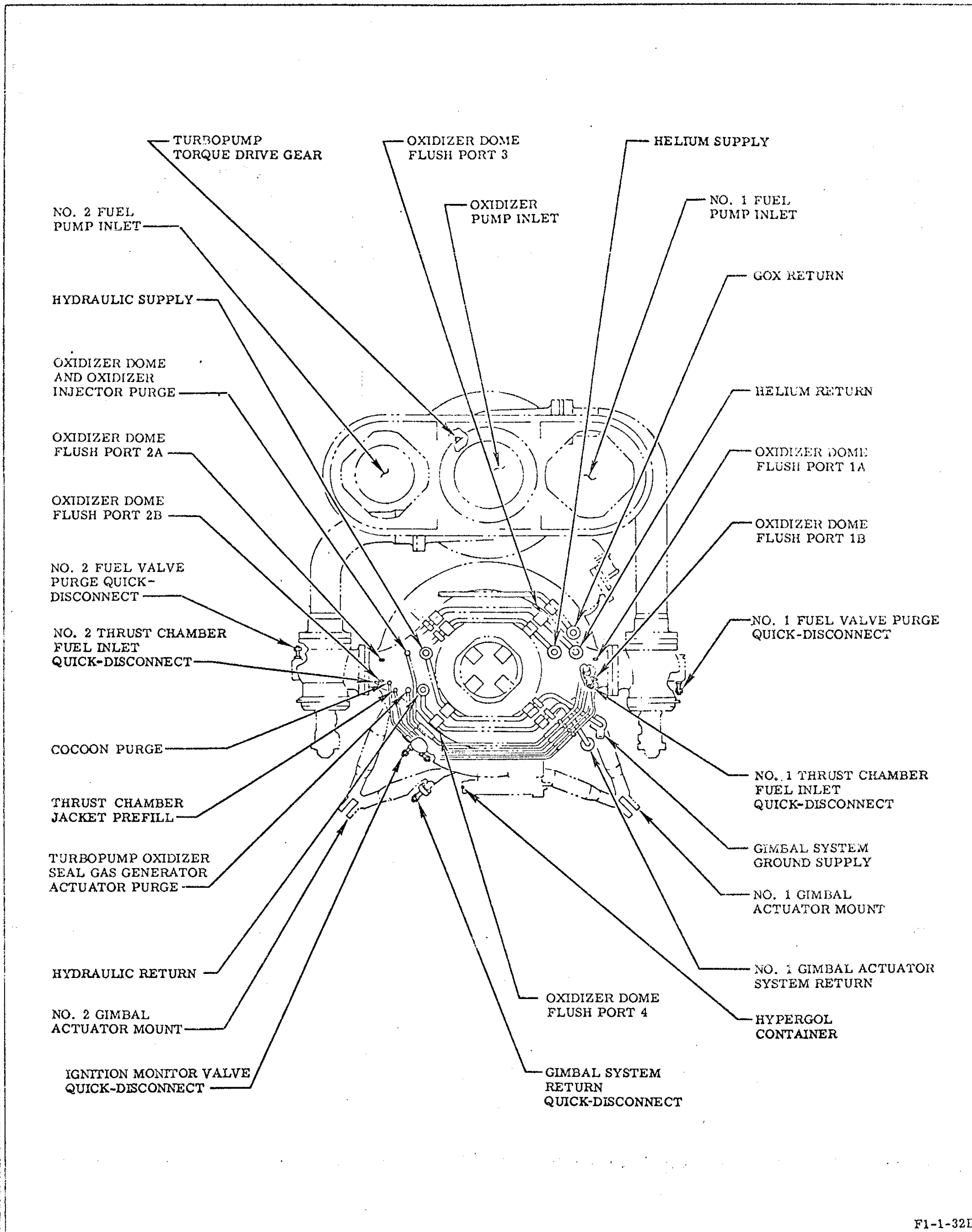


Figure 2-21. Operating and Servicing Interface Connections (Sheet 2 of 3)

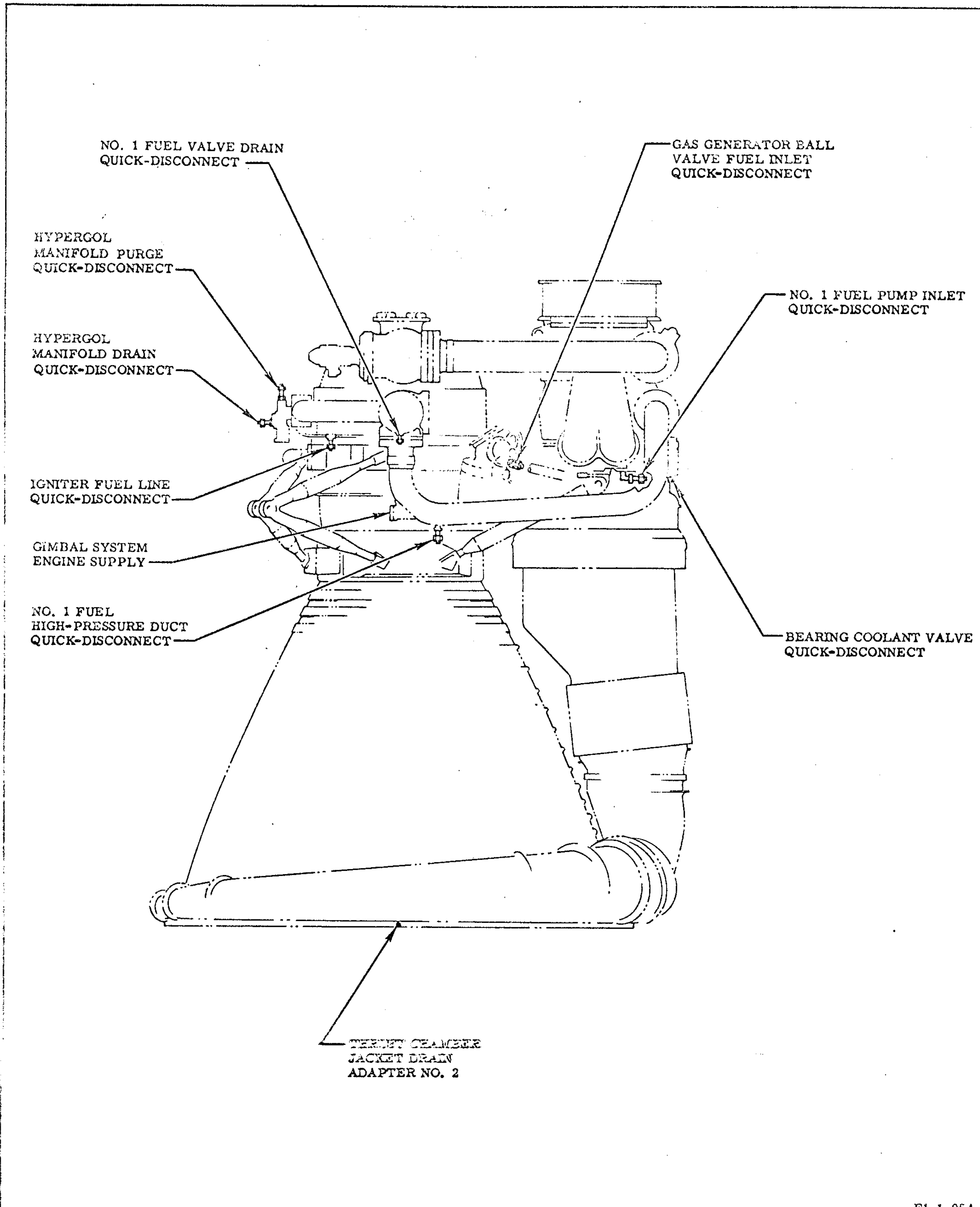


Figure 2-21. Operating and Servicing Interface Connections (Sheet 3 of 3)

Pages 2-19 through 2-22 deleted.

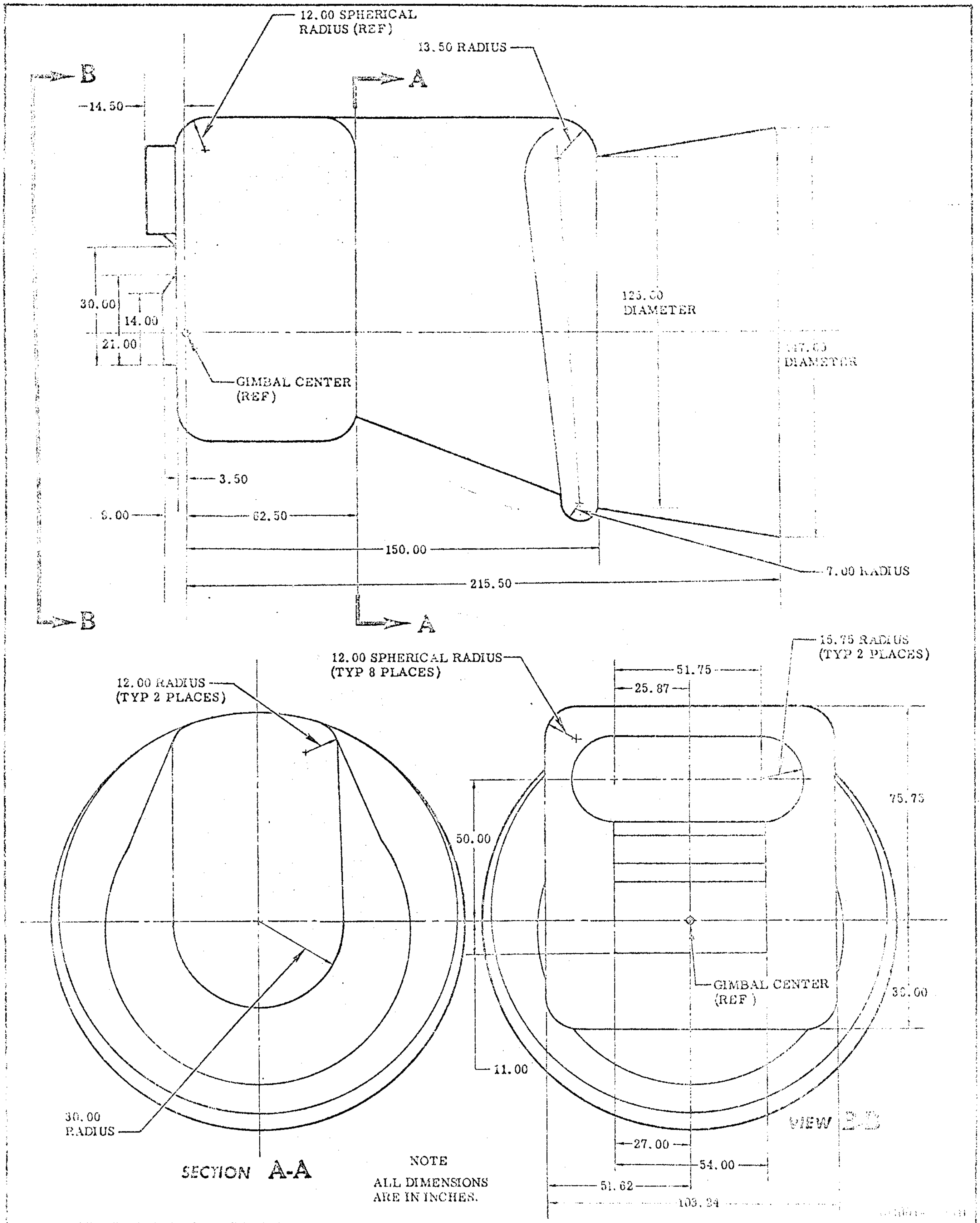


Figure 2-22. Engine Envelope Dimensions

Pin	Functional Description	Signal Origin	Signal Termination
	CONNECTOR J-18: Connector equivalent to an MS3101R36-10P with 48 contacts, size AWG #16		
	CAUTION		
	Pins k and m should be jumpered in mating connector P18 to make it electrically impossible to operate engine control valve opening solenoid or engine control valve closing without connector being secured.		
A thru Y	Spares		
Z	Turbopump Thermostat Control Package--Signal indicating normal heater temperature (output)	Engine	GSE
a	Turbopump Thermostat Control Package--Loss of signal indicates above normal heater temperature (output)	Engine	GSE
b	Turbopump Thermostat Control Package--Heater cycle signal (output)	Engine	GSE
c thru e	Spares		
f	Turbopump Thermostat Control Package--28 vdc power to thermostat control package (input)	GSE	Engine
g	Engine Control Valve--Closing solenoid energizing signal (input)	GSE	Engine

Pin	Functional Description	Signal Origin	Signal Termination
h	Vehicle Power Supply--Provides vehicle power to GSE (input)	Stage	GSE
j	Engine Control Valve--Negative return for opening and closing solenoid	Engine	Stage or GSE
k	Engine Control Valve--Negative return for opening solenoid through closing solenoid to make sure both connectors are secured	Engine	GSE
m	Engine Control Valve--Negative return for opening solenoid through closing solenoid to make sure both connectors are secured	Engine	GSE
n	Engine Control Valve--Opening solenoid energizing signal (input)	GSE	Engine
p	Checkout Valve--28 vdc signal to drive checkout valve motor to engine return position (input)	GSE	Engine
q	Checkout Valve--28 vdc signal to drive checkout valve motor to ground return position (input)	GSE	Engine

Figure 2-23. Electrical Interface Requirements (Sheet 1 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
r	Checkout Valve--Signal indicating valve in engine return position (output)	Engine	GSE
s	Checkout Valve--Signal indicating valve in ground return position (output)	Engine	GSE
t	Checkout Valve--Ground return for motor on checkout valve	Engine	GSE
u thru y	Spares		
z	Shielded Termination--Connects engine shielding to GSE shielding		
	CONNECTOR J-19: Connector equivalent to an MS3101R20-33P with 11 contacts, size AWG #16		
A	Spare		
B	Hypergol Cartridge--28 vdc power to cartridge switch common terminal (input)	GSE	Engine
C	Hypergol Cartridge--Signal indicating hypergol cartridge installed (output)	Engine	GSE
D	Redundant Shutdown Valve--28 vdc power energizing signal (input)	GSE	Engine
E	Spare		
F	Spare		
H	Spare		
H	Redundant Shutdown Valve--Monitoring signal	Engine	GSE
H[(a)]	Spare		
J	Spare		
K	Spare		

(a) Engines incorporating MD152 change

Figure 2-23. Electrical Interface Requirements (Sheet 2 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
L	Spare		
L	Redundant Shutdown Valve--Negative return	Engine	GSE
M	Shield Termination--Connects engine shielding to GSE shielding		
	CONNECTOR J-20: Connector equivalent to an MS3101R28-12P with 26 contacts, size AWG #16		
A thru D	Spares		
E	No. 1 Thrust OK Pressure Switch--Signal Indicating engine is not up to full thrust (output)	Engine	GSE
F	No. 1 Thrust OK Pressure Switch--28 vdc power (input)	GSE	Engine
G	No. 1 Thrust OK Pressure Switch--Signal indicating engine has developed satisfactory thrust (output)	Engine	GSE
H thru U	Spares		
V	Vehicle Power Supply--Negative return from GSE and engine control valve closing solenoid	Engine and GSE	Stage
W	Spare		
X	Spare		
Y	Vehicle Power Supply--Provides vehicle power to GSE	Stage	GSE
Z	Spare		
a	Spare		
b	Shielded Termination--Connects engine shielding to stage shielding		
d	Engine Control Valve--Closing solenoid energizing signal from vehicle; signal time duration to 100 ms (input)	Stage	Engine
	CONNECTOR J-100: Connector equivalent to an MS3101R20-16P with 9 contacts, sizes 2 AWG #12 and 7 AWG #16		
A	Positive 28 VDC Power Source for Primary Instrumentation System	Stage	Engine
B	28 VDC Power Return for Primary Instrumentation System	Stage	Engine
C	Positive 28 VDC Duplicate Power for Primary Instrumentation Valve Position Switches	Stage	Engine
D	5 VDC Duplicate Power Return and Pressure Transducer Signal Return for Primary Instrumentation System	Stage	Engine

Figure 2-23. Electrical Interface Requirements (Sheet 3 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
E thru H	Spares		
I	Shield Return for Primary Instrumentation System	Engine	Stage
	CONNECTOR J-101: Connector equivalent to an MS3101R28-21P with 37 contacts, size 37 AWG #16		
A	Positive 28 VDC Duplicate Power Source for Primary Instrumentation System	Stage	Engine
B	28 VDC Duplicate Power Return for Primary Instrumentation System	Stage	Engine
C	Positive 28 VDC Duplicate Power Source for Primary Instrumentation System Valve Position Switches	Stage	Engine
D	5 VDC Duplicate Power Return and Pressure Transducer Signal Return for Primary Instrumentation System	Stage	Engine
E thru J	Spares		
K	Common Hydraulic Return Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-126)	GSE	Engine
L	Combustion Chamber Pressure Transducer Signal Output (D-8)	Engine	Stage
M	Combustion Chamber Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-8)	GSE	Engine
N	Combustion Chamber Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-8)	GSE	Engine
P	Spare		
R	Spare		
S	Common Hydraulic Return Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-126)	GSE	Engine
T	Turbine Outlet Pressure Transducer Signal Output (D-10)	Engine	Stage
U	Turbine Outlet Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-10)	GSE	Engine

Figure 2-23. Electrical Interface Requirements (Sheet 4 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
V	Turbine Outlet Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-10)	GSE	Engine
W	Gas Generator Chamber Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-9)	GSE	Engine
X	Gas Generator Chamber Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-9)	GSE	Engine
Z	Spare		
a	Common Hydraulic Return Pressure Transducer Signal Output (D-126)	Engine	Stage
b	LOX Pump Bearing Jet Pressure Transducer Signal Output (D-13)	Engine	Stage
c	LOX Pump Bearing Jet Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-13)	GSE	Engine
d	LOX Pump Bearing Jet Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-13)	GSE	Engine
e	Fuel Pump Inlet No. 1 Pressure Transducer Signal Output (D-4)	Engine	Stage
f	Gas Generator Chamber Pressure Transducer Signal Output (D-9)	Engine	Stage
g	LOX Pump Discharge No. 2 Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-3)	GSE	Engine
h	Fuel Pump Discharge No. 2 Pressure Transducer Signal Output (D-7)	Engine	Stage
j	Fuel Pump Discharge No. 2 Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-7)	GSE	Engine
k	Fuel Pump Inlet No. 1 Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-4)	GSE	Engine
m	Fuel Pump Inlet No. 1 Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-4)	GSE	Engine
n	LOX Pump Discharge No. 2 Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-3)	GSE	Engine
p	LOX Pump Discharge No. 2 Pressure Transducer Signal Output (D-3)	Engine	Stage

Figure 2-23. Electrical Interface Requirements (Sheet 5 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
r	Fuel Pump Discharge No. 2 Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-7)	GSE	Engine
s	Shield Return	Engine	Stage
	CONNECTOR J102: Connector equivalent to an MS3101R22-14P with 19 contacts, size 19 AWG #16		
A	Spare		
B	No. 1 Main Fuel Valve Position Potentiometer Signal Output (K-7)	Engine	Stage
C	Positive 5 VDC Excitation for No. 1 Main Fuel Position Potentiometer (K-7)	Stage	Engine
D	No. 2 Main Fuel Valve Position Potentiometer Signal Output (K-8)	Engine	Stage
E	Output Signal No. 1 Main LOX Valve Position Potentiometer Signal Output (K-9)	Engine	Stage
F	Positive 5 VDC Excitation for No. 1 Main LOX Valve Position Potentiometer (K-9)	Stage	Engine
G	5 VDC Return for No. 1 Main LOX Valve Position Potentiometer (K-9)	Stage	Engine
H	No. 2 Main LOX Valve Position Potentiometer Signal Output (K-10)	Engine	Stage
J	Positive 5 VDC Excitation for No. 2 Main LOX Valve Position Potentiometer (K-10)	Engine	Engine
K thru N	Spares		
P	5 VDC Return for No. 1 Main Fuel Valve Position Potentiometer (K-7)	Stage	Engine
R	Positive 5 VDC Excitation for No. 2 Main Fuel Valve Position Potentiometer (K-8)	Stage	Engine
S	5 VDC Return for No. 2 Main Fuel Valve Position Potentiometer (K-8)	Stage	Engine
T	5 VDC Return for No. 2 Main LOX Valve Position Potentiometer (K-10)	Stage	Engine
U	Spare		
V	Shield Return	Engine	Stage
	CONNECTOR J-103: Connector equivalent to an MS3101R22-14S with 19 contacts, size 19 AWG #16		
A	Spare		
B	Spare		

Figure 2-23. Electrical Interface Requirements (Sheet 6 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
C	Gas Generator Valve Limit Switch Open Signal (K-6)	Engine	Stage
D	Gas Generator Valve Limit Switch Closed Signal (K-6)	Engine	Stage
E	No. 1 Main Fuel Valve Limit Switch Open Signal (K-7)	Engine	Stage
F	No. 1 Main Fuel Valve Limit Switch Closed Signal (K-7)	Engine	Stage
G	No. 2 Main Fuel Valve Limit Switch Open Signal (K-8)	Engine	Stage
H	No. 2 Main Fuel Valve Limit Switch Closed Signal (K-8)	Engine	Stage
J	No. 2 Main LOX Valve Limit Switch Open Signal (K-10)	Engine	Stage
K thru N	Spares		
P	Vehicle Engine Cutoff Signal Received at Engine Cutoff Solenoid (Reference) (K-13)	Engine	Stage
R	Closed Signal, No. 1 Main LOX Valve Limit Switch (K-9)	Engine	Stage
S	No. 1 Main LOX Valve Limit Switch Open Signal (K-9)	Engine	Stage
T	No. 2 Main LOX Valve Limit Switch Closed Signal (K-10)	Engine	Stage
U	Spare		
V	Shield Return	Engine	Stage
	CONNECTOR J-104: Connector equivalent to an MS3101R20-27P with 14 contacts, size 14 AWG #16		
A	Spare		
B	Spare		
C	Turbopump Tachometer Signal Output, (T-1). Signal frequency is proportional to turbopump angular speed.	Engine	Stage
D	Turbopump Tachometer Calibration and Checkout Voltage Input (T-1)	GSE	Engine
E	Heat Exchanger LOX Inlet Flowmeter ±Signal Output (T-44)	Engine	Stage
F	Heat Exchanger Inlet Flowmeter Signal Output (T-44)	Engine	Stage

Figure 2-23. Electrical Interface Requirements (Sheet 7 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
G	Heat Exchanger LOX Inlet Flowmeter Calibration and Checkout Voltage ±Input (T-44)	GSE	Engine
H	Heat Exchanger LOX Inlet Flowmeter Calibration and Checkout Voltage Input (T-44)	GSE	Engine
I thru K	Spare		
L	Turbopump Tachometer ±Signal Output (T-1). Signal frequency is proportional to turbopump angular speed.	Engine	GSE
M	Turbopump Tachometer Calibration and Checkout Voltage ±Input (T-1)	GSE	Engine
N	Shield Return	Engine	Stage

<u>CONNECTOR J-106</u>: Connector equivalent to an MS3101R20-29P with 17 contacts, size 17 AWG #16

Pin	Functional Description	Signal Origin	Signal Termination
A	Spare		
B	Spare		
C	Turbine Inlet Temperature Resistance Thermometer Sensor Output (C-3)	Stage	Engine
D	LOX Pump Bearing No. 1 Temperature Resistance Thermometer, Input Common (C-6)	Stage	Engine
E	LOX Pump Bearing No. 1 Temperature Resistance Thermometer, Output Common (C-6)	Engine	Stage
F	Engine Environmental Temperature Resistance Thermometer, Input Common (C-943)	Stage	Engine
G	Engine Environmental Temperature Resistance Thermometer, Output Common (C-943)	Engine	Stage
H	LOX Pump Bearing No. 2 Temperature Resistance Thermometer Sensor Output (C-7)	Stage	Engine

Figure 2-23. Electrical Interface Requirements (Sheet 8 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
H	Engine Environmental Temperature Resistance Thermometer, Sensor Output (C-943)	Engine	Stage
J	Spare		
K	Spare		
L	Spare		
M	Spare		
N	Turbine Inlet Temperature Resistance Thermometer Input Common (C-3)	Stage	Engine
P	Turbine Inlet Temperature Resistance Thermometer Output Common (C-3)	Engine	Stage
R	LOX Pump Bearing No. 1 Temperature Resistance Thermometer, Sensor Output (C-6)	Stage	Engine
S	Turbine Bearing Temperature Resistance Thermometer, Sensor Output (C-8)	Stage	Engine
S	Spare		
T	Shield Return	Engine	Stage
	CONNECTOR J-140:[b] Connector equivalent to an MS3101R16S-8P with 5 contacts, size 5 AWG #16		
A	Positive 28 VDC Duplicate Power for Auxiliary Instrumentation System	Stage	Engine
B	28 VDC Duplicate Power Return for Auxiliary Instrumentation System	Stage	Engine
C	Spare		
D	5 VDC Duplicate Return and Pressure Transducer Signal Return for Auxiliary Instrumentation System	Stage	Engine
E	Shield Return for Auxiliary Instrumentation System	Engine	Stage
	CONNECTOR J-141:[b] Connector equivalent to an MS3101R36-7P with 47 contacts, sizes 40 AWG #16 and 7 AWG #12		
A	Positive 28 VDC Duplicate Power Source for Auxiliary Instrumentation System	Stage	Engine
B	28 VDC Duplicate Power Return for Auxiliary Instrumentation System	Stage	Engine
C	28 VDC Duplicate Power Return for Auxiliary Instrumentation System	Stage	Engine

(b) Engines not incorporating MD96 or MD97 change

Figure 2-23. Electrical Interface Requirements (Sheet 9 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
D	5 VDC Duplicate Power Return and Pressure Transducer Output Common for Auxiliary Instrumentation System	Stage	Engine
E	Spare		
F	LOX Pump Discharge No. 1 Pressure Transducer Signal Output (D-2)	Engine	Stage
G	Spare		
H	LOX Pump Discharge No. 1 Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-2)	GSE	Engine
I	Spare		
J	Output Signal, Engine Control Closing Pressure Transducer (D-11)	Engine	Stage
K	Spare		
L	LOX Pump Discharge No. 1 Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-2)	GSE	Engine
M	Engine Control Closing Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-11)	GSE	Engine
N	Engine Control Opening Pressure Transducer Signal Output (D-12)	Engine	Stage
O	Spare		
P	Spare		
R	Engine Control Closing Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-11)	GSE	Engine
S	Engine Control Opening Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-12)	GSE	Engine
T	Fuel Pump Discharge No. 1 Pressure Transducer Signal Output (D-6)	Engine	Stage
U	Spare		
V	Spare		
W	Engine Control Opening Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-12)	GSE	Engine
X	Spare		

Figure 2-23. Electrical Interface Requirements (Sheet 10 of 14)

Pin	Functional Description	Signal Origin	Signal Termination	Pin	Functional Description	Signal Origin	Signal Termination
Y	Heat Exchanger Helium Inlet Pressure Transducer Signal Output (D-19)	Engine	Stage	j	Heat Exchanger Helium Inlet Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-19)	GSE	Engine
Z	Spare			k	LOX Pump Seal Cavity Pressure 80-Percent Calibration and Checkout Voltage Input (D-142)	GSE	Engine
a	Heat Exchanger Helium Inlet Pressure Transducer Signal Output (D-20)	Engine	Stage	m	Heat Exchanger LOX Inlet Pressure Transducer Signal Output (D-17)	Engine	Stage
b	Spare			n	Heat Exchanger Gaseous Oxygen Outlet Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-18)	GSE	Engine
c	LOX Pump Seal Cavity Pressure Transducer Signal Output (D-142)	Engine	Stage	p	Heat Exchanger LOX Inlet Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-17)	GSE	Engine
d	Heat Exchanger Helium Inlet Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-19)	GSE	Engine	r	Heat Exchanger Gaseous Oxygen Outlet Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-18)	GSE	Engine
e	Heat Exchanger Helium Outlet Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-20)	GSE	Engine	s	Heat Exchanger LOX Inlet Pressure 80-Percent Calibration and Checkout Voltage Input (D-17)	GSE	Engine
f	Heat Exchanger Helium Outlet Pressure Transducer 80-Percent Calibration and Checkout Voltage Input (D-20)	GSE	Engine	t thru y	Spares		
g	LOX Pump Seal Cavity Pressure Transducer 20-Percent Calibration and Checkout Voltage Input (D-142)	GSE	Engine				
h	Heat Exchanger Gaseous Oxygen Outlet Pressure Transducer Output Signal (D-18)	Engine	Stage	z	Shield Return	Engine	Stage

Figure 2-23. Electrical Interface Requirements (Sheet 11 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
	CONNECTOR J-142:		
A	No. 2 Thrust OK Pressure Switch--Signal indicating engine is not up to full thrust (output)	Engine	GSE
B	No. 2 Thrust OK Pressure Switch--28 vdc power (input)	GSE	Engine
C	No. 2 Thrust OK Pressure Switch--Signal indicating engine has developed satisfactory thrust (output)	Engine	GSE
D	Shield Termination--Connects engine shielding to S-IC stage shielding		
	CONNECTOR J-143:[b]	Connector equivalent to an MS3101R24-28P with 28 contacts, size 24 AWG #16	
A thru H	Spares		
J	Heat Exchanger LOX Inlet Temperature Resistance Thermometer Input Common (C-11)	Stage	Engine
K	Fuel Pump Inlet No. 2 Temperature Resistance Thermometer Input Common (C-24)	Stage	Engine
L	Fuel Pump Inlet No. 2 Temperature Resistance Thermometer Output Common (C-24)	Engine	Stage
M	Fuel Pump Inlet No. 2 Temperature Resistance Thermometer Sensor Output (C-24)	Stage	Engine
N	Heat Exchanger LOX Inlet Temperature Resistance Thermometer Output Common (C-11)	Engine	Stage
P	Heat Exchanger LOX Inlet Temperature Resistance Thermometer Sensor Output (C-11)	Stage	Engine
Q	Heat Exchanger Helium Outlet Temperature Resistance Thermometer Input Common (C-13)	Stage	Engine
R	Heat Exchanger Gaseous Oxygen Outlet Temperature Resistance Thermometer Input Common (C-12)	Stage	Engine

(b) Engines not incorporating MD96 or MD97 change

Figure 2-23. Electrical Interface Requirements (Sheet 12 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
S	Heat Exchanger Gaseous Oxygen Outlet Temperature Resistance Thermometer Output Common (C-12)	Engine	Stage
T	Heat Exchanger Gaseous Oxygen Outlet Temperature Resistance Thermometer Sensor Output (C-12)	Stage	Engine
U	Heat Exchanger Helium Outlet Temperature Resistance Thermometer Output Common (C-13)	Engine	Stage
V	Heat Exchanger Helium Outlet Temperature Resistance Thermometer Sensor Outlet (C-13)	Stage	Engine
W thru Y	Spares		
Z	Shield Return	Engine	Stage
	CONNECTOR J-174:		
A	No. 3 Thrust OK Pressure Switch--Signal indicating engine is not up to full thrust (output)	Engine	GSE
B	No. 3 Thrust OK Pressure Switch--28 vdc power (input)	GSE	Engine
C	No. 3 Thrust OK Pressure Switch--Signal indicating engine has developed satisfactory thrust (output)	Engine	GSE
D	Spare		
E	Shielding Termination--Connects engine shielding to S-1C stage shielding		
	CONNECTOR J-470: Connector equivalent to an MS3101R28-12P with 26 contacts, size AWG #16		
A	Spare		
B	Gas Generator Igniter No. 1 and No. 2--Continuity-checks through igniter links No. 1 and No. 2 indicating igniters installed (input)	GSE	Engine
C	Gas Generator Igniter No. 1 and No. 2--Continuity-checks through igniter links No. 1 and No. 2 indicating igniters installed (input)	GSE	Engine
D	Turbine Exhaust Igniter No. 1--500 vac to turbine exhaust igniter No. 1 (input)	Engine	GSE
E and F	Spares		
G	Gas Generator Igniter No. 2--500 vac to gas generator igniter No. 2 squib (input)	GSE	Engine
H	Spare		
J	Turbine Exhaust Igniter No. 2--500 vac to turbine exhaust igniter No. 2 squib (input)	GSE	Engine
K	Spare		
L	Spare		

Figure 2-23. Electrical Interface Requirements (Sheet 13 of 14)

Pin	Functional Description	Signal Origin	Signal Termination
M	Gas Generator Igniter No. 1--500 vac to gas generator igniter No. 1 squib (input)	GSE	Engine
N	Spare		
P	Turbine Exhaust Igniter No. 1 and No. 2--Continuity-checks through igniter links No. 1 and No. 2 indicating igniters installed (input)	GSE	Engine
R	Turbine Exhaust Igniter No. 1 and No. 2--Continuity-checks through igniter links No. 1 and No. 2 indicating igniters installed	GSE	Engine
S	Spare		
T	Turbine Exhaust Igniter No. 1--500 vac to turbine exhaust igniter No. 1 squib (input)	GSE	Engine
U	Spare		
V	Gas Generator Igniter No. 2--500 vac to gas generator igniter No. 2 squib (input)	GSE	Engine
W and X	Spare		
Y	Turbine Exhaust Igniter No. 2--500 vac to turbine exhaust igniter No. 2 squib (input)	GSE	Engine
Z	Spare		
a	Gas Generator Igniter No. 1--500 vac to gas generator igniter No. 1 squib (input)	GSE	Engine
b	Spare		
d	Shield Termination--Connects engine shielding to GSE shielding	Engine	GSE
CONNECTOR J-800	Connector equivalent to MS3[illegible]18-1P with [illegible] contacts, size AWG #16		
A and B	Spare		
C	Turbopump Heater No. 1--208 vac power to turbopump heater No. 1 (input)	GSE	Engine
D	Turbopump Heater No. 1--208 vac power to turbopump heater No. 1 (input)	GSE	Engine
E	Turbopump Heater No. 2--208 vac power to turbopump heater No. 2 (input)	GSE	Engine
F	Turbopump Heater No. 2--208 vac power to turbopump heater No. 2 (input)	GSE	Engine
G thru I	Spare		
J	Shield Termination--Connects engine shielding to GSE shielding	Engine	GSE

Figure 2-23. Electrical Interface Requirements (Sheet 14 of 14)

2-47. INSTRUMENTATION TAP LOCATIONS AND IDENTIFICATION.

2-48. TAP CODE IDENTIFICATION SYSTEM. Tap locations are shown in figure 2-24. The code identification system is as follows:

A, actuator

C, thrust chamber

[illegible], gas generator

[illegible], heat exchanger

[illegible], igniter fuel injection

[illegible], low-pressure propellant

[illegible], turbopump

[illegible], control system

[illegible], main propellant

[illegible], turbine

[illegible], gimbal

The second-column capital letter designates the medium being sensed or the operating feature connected with the tap as follows:

[illegible], propellant fuel

[illegible], high-temperature gas

H, hydraulic control liquid or helium

L, lubricant

S, metal temperature

B, bearing

[illegible], propellant oxidizer

The third-column number identifies the tap on the component or in the system.

The fourth-column lower case letter signifies more than one tap of the same measurement.

The fifth-column number signifies that the tap location is duplicated on both the No. 1 and No. 2 sides of the engine.

2-49. ACCELEROMETER CODE IDENTIFICATION SYSTEM. Accelerometer locations are shown in figure 2-24. The code identification system is as follows:

The first-column capital letter designates major component or basic support system as follows:

C, thrust chamber

P, turbopump

M, interface panel

The second-column capital letter designates the medium being sensed or the operating feature connected with the tap as follows:

Z, no fluid medium involved

The third-column capital letter identifies the type of measuring instrument as follows:

A, accelerometer

The fourth-column number identifies the tap on the component or in the system.

The fifth-column letter identifies the axis sensitivity of the accelerometer.

Pages 2-39 through 2-46 deleted.

3-38. ENGINE INFLUENCE COEFFICIENTS.

3-39. Engine influence coefficients result from a linear solution of a set of steady-state equations which describe the operation of an engine. Each influence coefficient is expressed in percentage form and represents the effect upon an engine dependent variable of a plus-one-percent change in an engine independent variable. Because the influence coefficients are linear, the total effect of several influences acting simultaneously on an engine can be determined by adding the individual effects of each influence. A coefficient preceded by a positive (+) sign, or no sign, indicates that an increase in the independent variable results in an increase in the dependent variable; a coefficient preceded by a negative (-) sign indicates that an increase in the independent variable results in a decrease in the dependent variable. Figure 3-39 contains sets of the current predicted engine influence coefficients and, when calculations are required, these sets may be used. Paragraphs 3-39 through 3-43 describe the use of the engine influence coefficients using the formula

$$\frac{F_E - F_{E_i}}{F_{E_N}} = \frac{P_a - P_{a_i}}{P_{a_N}}(F_{P_a}) + \frac{T_F - T_{F_i}}{T_{F_N}}(F_{T_F}) + \frac{\rho_F - \rho_{F_i}}{\rho_{F_N}}(F_{\rho_F}) + \frac{\rho_O - \rho_{O_i}}{\rho_{O_N}}(F_{\rho_O}) + \frac{P_F - P_{F_i}}{P_{F_N}}(F_{P_F}) + \frac{P_O - P_{O_i}}{P_{O_N}}(F_{P_O})$$

when the quantities are defined as follows:

NOTE

The values in g, k, and o are from the influence coefficient tables (figure 3-39).

a. F_E = Engine thrust--actual value

b. F_{E_i} = Engine thrust--initial or base value

c. F_{E_N} = Engine thrust--nominal value

d. P_a = Ambient pressure--actual value

e. P_{a_i} = Ambient pressure--initial or base value

f. P_{a_N} = Ambient pressure--nominal value

g. F_{P_a} = Ambient pressure--influence coefficient

gA. T_F = Fuel temperature--actual value

gB. T_{F_i} = Fuel temperature--initial or base value

gC. T_{F_N} = Fuel temperature--nominal value

gD. F_{T_F} = Fuel temperature--influence coefficient

h. ρ_F and ρ_O = Fuel (F) and Oxidizer (O) density--actual value

i. ρ_{F_i} and ρ_{O_i} = Fuel (F) and Oxidizer (O) density--initial or base value

j. ρ_{F_N} and ρ_{O_N} = Fuel (F) and Oxidizer (O) density--nominal value

k. F_{ρ_F} and F_{ρ_O} = Fuel (F) and Oxidizer (O) density--influence coefficient value

l. P_F and P_O = Fuel (F) and Oxidizer (O) pump inlet pressure--actual value

m. P_{F_i} and P_{O_i} = Fuel (F) and Oxidizer (O) pump inlet pressure--initial or base value

n. P_{F_N} and P_{O_N} = Fuel (F) and Oxidizer (O) pump inlet pressure--nominal value

o. F_{P_F} and F_{P_O} = Fuel (F) and Oxidizer (O) pump inlet pressure--influence coefficient value

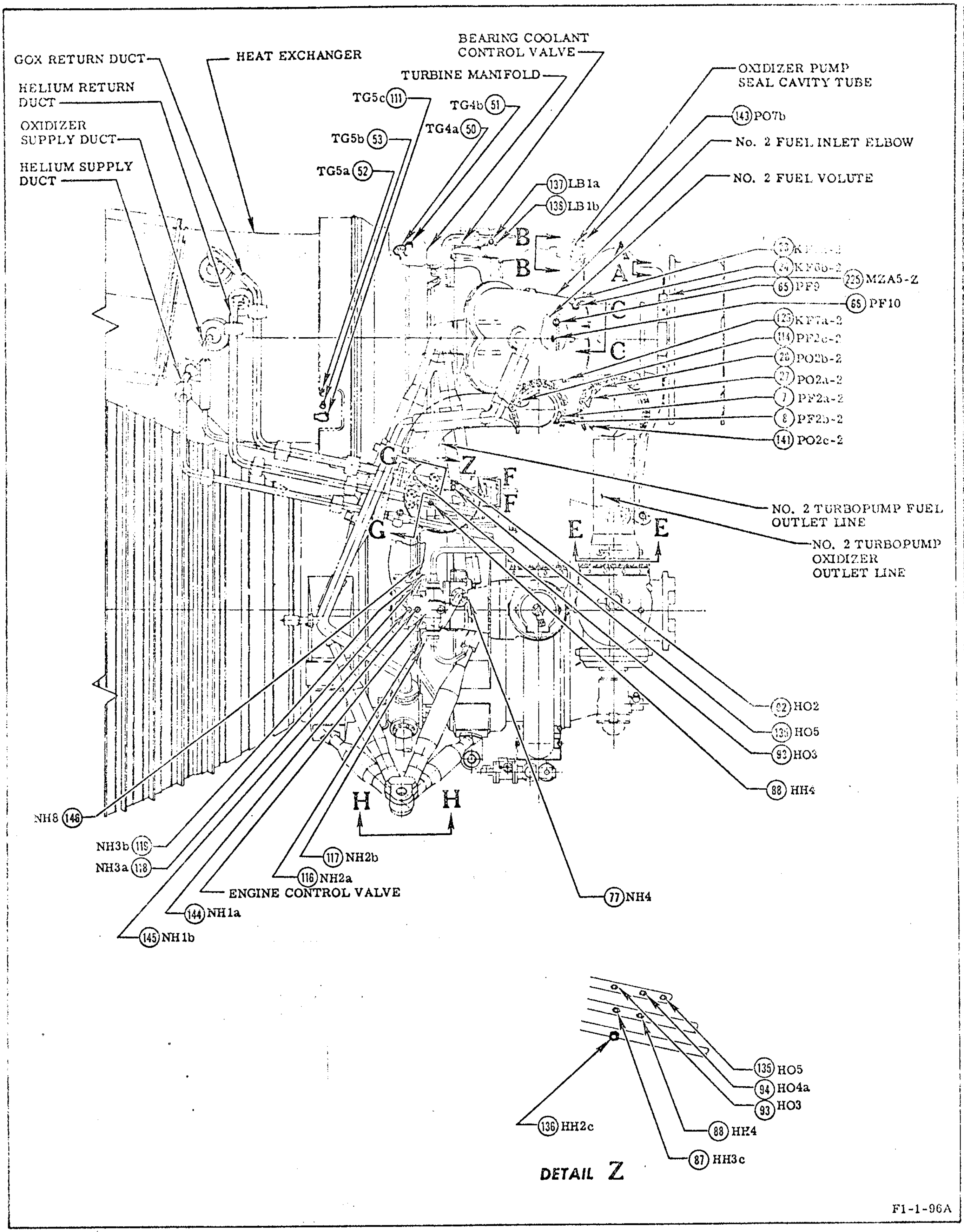


Figure 2-24. Instrumentation Tap Locations (Sheet 1 of 8)

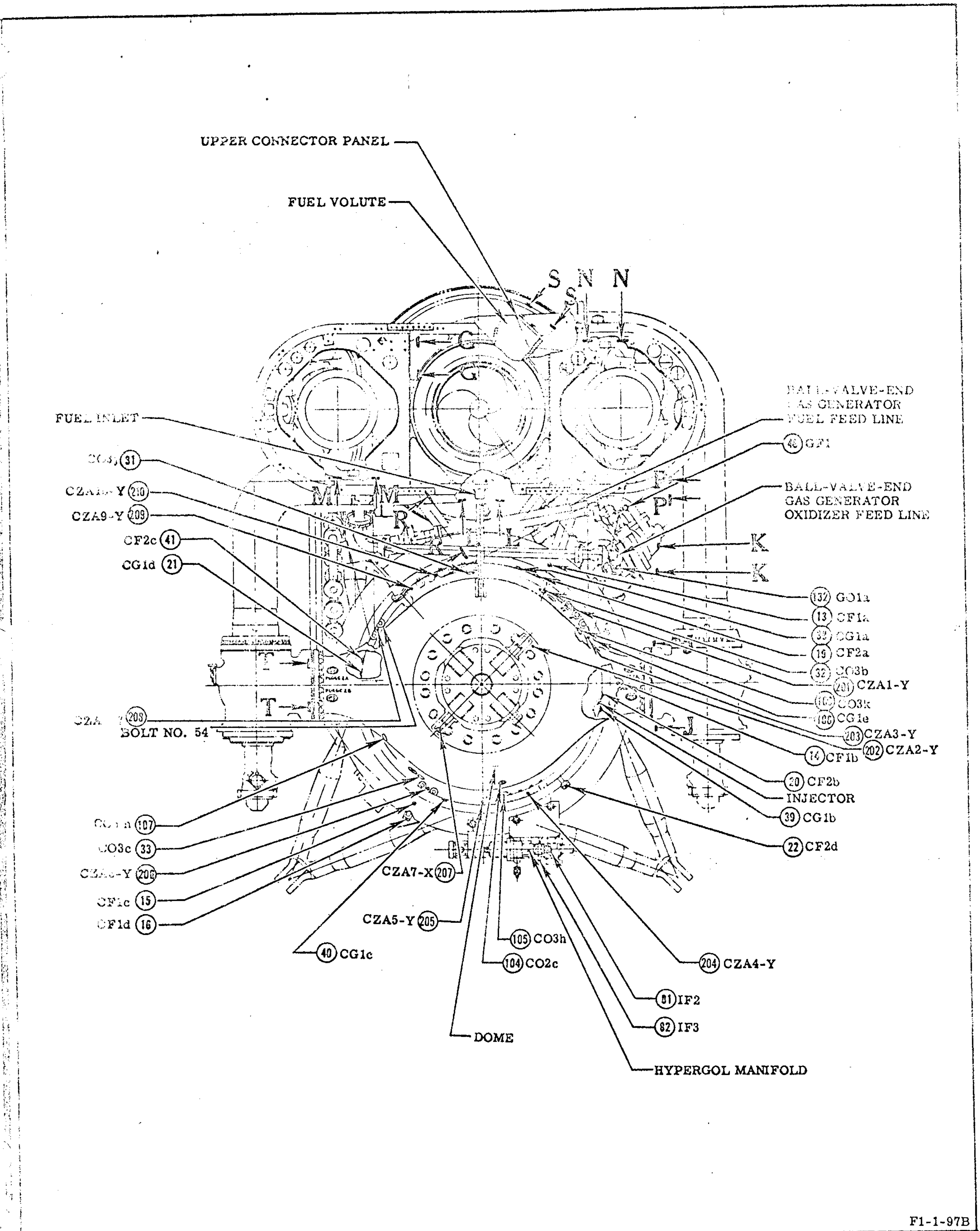


Figure 2-24. Instrumentation Tap Locations (Sheet 2 of 8)

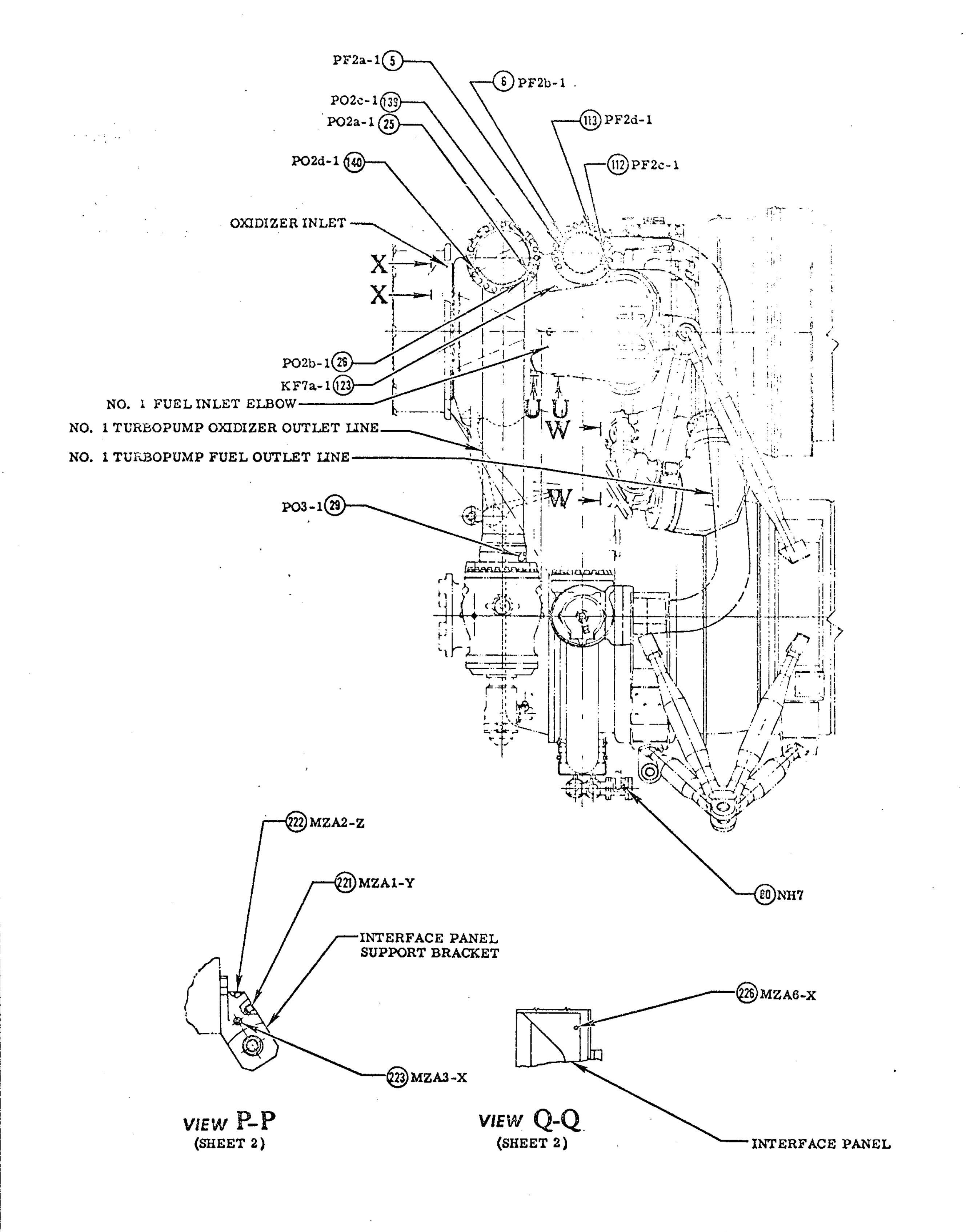


Figure 2-24. Instrumentation Tap Locations (Sheet 3 of 8)

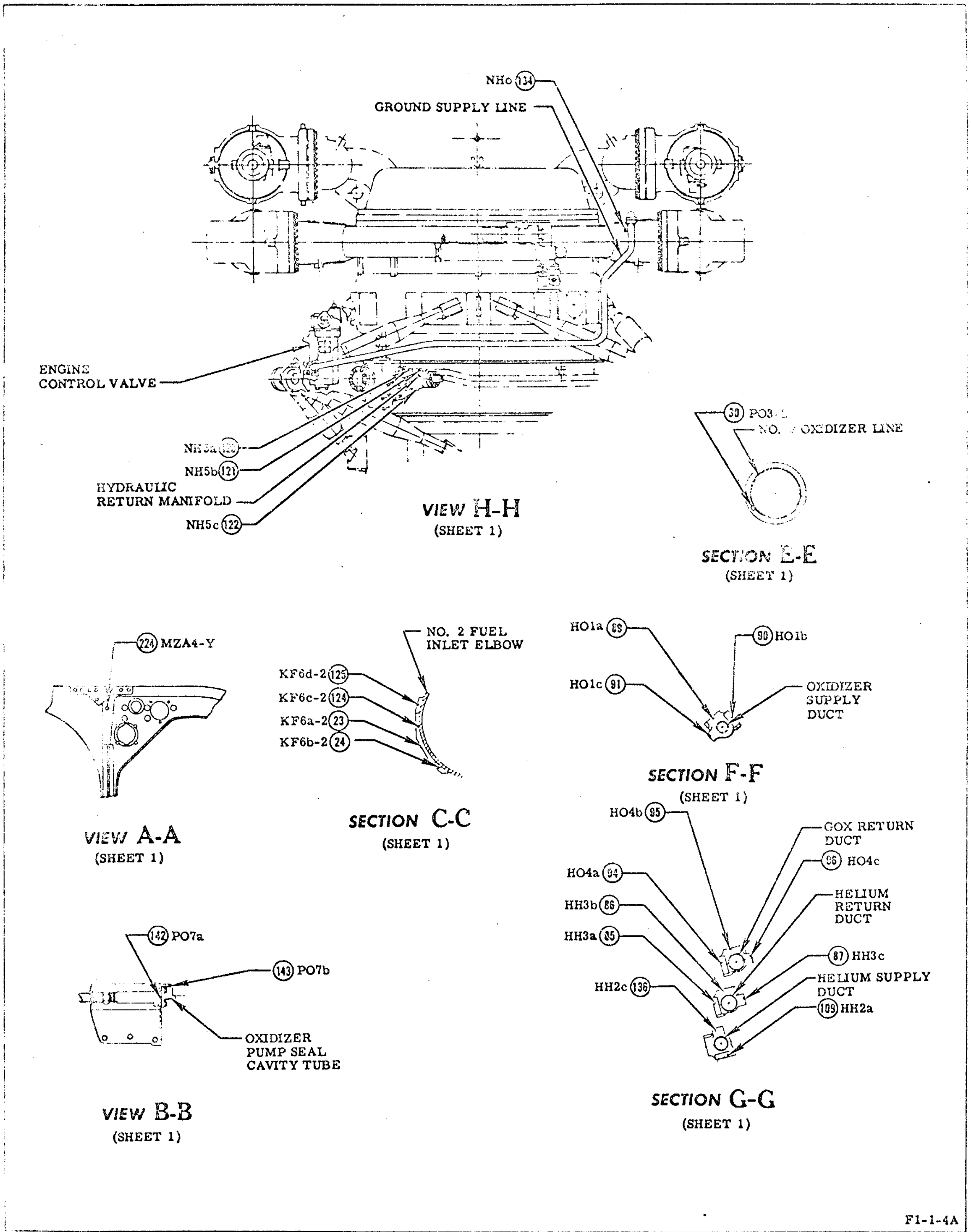


Figure 2-24. Instrumentation Tap Locations (Sheet 4 of 8)

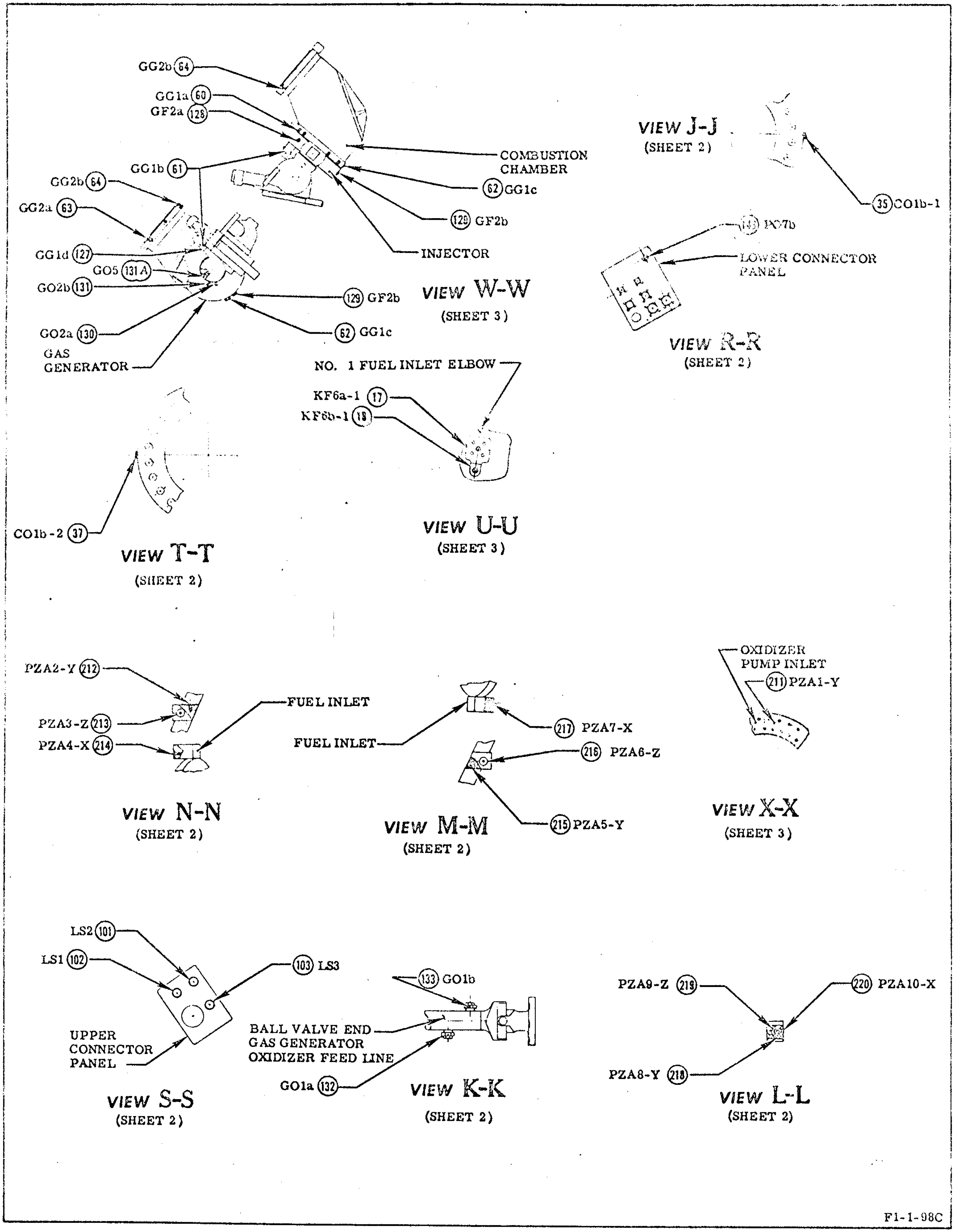


Figure 2-24. Instrumentation Tap Locations (Sheet 5 of 8)

Item No.	Tap No.	Description	Type
5(a)	PF2a-1	Fuel pump discharge No. 1	Flange
6(e)	PF2b-1	Fuel pump discharge No. 1	AND10050-4
7	PF2a-2	Fuel pump discharge No. 2	Flange
8	PF2b-2	Fuel pump discharge No. 2	AND10050-4
9	PF3a-1	No. 1 fuel valve inlet	RP260-1001
11	PF3a-2	No. 2 fuel valve inlet	AND10050-4
13	CF1a	Fuel manifold	RP260-1001
14(b)	CF1b	Fuel manifold	RP260-1001
15	CF1c	Fuel manifold	RP260-1001
16	CF1d	Fuel manifold	Flange
17	KF6a-1	Fuel pump inlet No. 1	Flange
18	KF6b-1	Fuel pump inlet No. 1	RP260-1001
19	CF2a	Fuel injection	RP260-1001
20(b)	CF2b	Fuel injection	RP260-1001
21	CF2c	Fuel injection	RP260-1001
22	CF2d	Fuel injection	Flange
23(a)	KF6a-2	Fuel pump inlet No. 2	Flange
24(d)	KF6b-2	Fuel pump inlet No. 2	RP260-1001
25	PO2a-1	Oxidizer pump discharge No. 1	Flange
26	PO2b-1	Oxidizer pump discharge No. 1	AND10050-4
27	PO2a-2	Oxidizer pump discharge No. 2	Flange
28(e)	PO2b-2	Oxidizer pump discharge No. 2	AND10050-4
29	PO3-1	No. 1 oxidizer valve inlet	RP260-1001
30	PO3-2	No. 2 oxidizer valve inlet	RP260-1001
31	CO3j	Oxidizer injection	AND10050-4
32(b)	CO3b	Oxidizer injection	AND10050-4
33	CO3c	Oxidizer injection	AND10050-4
35	CO1b-1	Oxidizer dome inlet No. 1	RP260-1001
37	CO1b-2	Oxidizer dome inlet No. 2	RP260-1001

Item No.	Tap No.	Description	Type
38	CG1a	Combustion chamber	RP260-1001
39(e)	CG1b	Combustion chamber	RP260-1001
40(c)	CG1c	Combustion chamber	RP260-1001
41(e)	CG1d	Combustion chamber	RP260-1001
46	GF1	Gas generator fuel valve inlet	RP260-1001
50	TG4a	Turbine inlet (manifold)	Flange
51	TG4b	Turbine inlet (manifold)	RP260-1001
52	TG5a	Turbine outlet	RP260-1001
53	TG5b	Turbine outlet	RP260-1001
60(b)	GG1a	Gas generator chamber	RP260-1001
61	GG1b	Gas generator chamber	AND10050-4
62	GG1c	Gas generator chamber	RP260-1001
63	GG2a	Turbine inlet	RP260-1001
64(f)	GG2b	Turbine inlet	RP260-1001
65	PF9	Fuel seal cavity	MS33656-5
66	PF10	Fuel impeller back casing	MS33656-5
77(b)	NH4	Engine control system return	RP260-1001
80(b)	NH7	Ignition monitor valve outlet	AND10050-4
81	IF2	Fuel igniter valve inlet	AND10050-4
82	IF3	Hypergol container inlet	RP260-1001
85(a)	HH3a	Heat exchanger helium outlet	Flange
86(a)	HH3b	Heat exchanger helium outlet	Flange
87	HH3c	Heat exchanger helium outlet	RP260-1001
88	HH4	Heat exchanger helium outlet	RP260-1001
89(a)	HO1a	Heat exchanger oxidizer inlet	Flange
90(a)	HO1b	Heat exchanger oxidizer inlet	Flange

(a) Engines not incorporating MD96 or MD97 change
(b) Engines not incorporating MD140 change
(c) Engines not incorporating MD177 change
(d) Engines not incorporating MD146 change
(e) Engines not incorporating MD141 change
(f) Engines not incorporating MD176 change

Figure 2-24. Instrumentation Tap Locations (Sheet 6 of 8)

Item No.	Tap No.	Description	Type
91	HO1c	Heat exchanger oxidizer inlet	RP260-1001
92	HO2	Heat exchanger oxidizer inlet	RP260-1001
93	HO3	Heat exchanger GOX outlet	RP260-1001
94[a]	HO4a	Heat exchanger GOX outlet	Flange
95[a]	HO4b	Heat exchanger GOX outlet	Flange
96	HO4c	Heat exchanger GOX outlet	RP260-1001
101	LS1	Bearing No. 1	MS33682-5
102	LS2	Bearing No. 2	MS33682-2
103	LS3	Turbine bearing	MS33682-3
104[b]	CO2c	Oxidizer manifold	AND10050-4
105	CO3h	Oxidizer injection	AND10050-4
106[b]	CO3k	Oxidizer injection	AND10050-4
107[b]	CO3m	Oxidizer injection	AND10050-4
108	CG1e	Combustion chamber	Flange
109[a]	HH2a	Heat exchanger helium inlet	Flange
111	TG5c	Turbine outlet	Flange
112[d]	PF2c-1	Fuel pump discharge No. 1	RP260-1001
113	PF2d-1	Fuel pump discharge No. 1	RP260-1001
114	PF2c-2	Fuel pump discharge No. 2	RP260-1001
116[a]	NH2a	Engine control closing	Flange
117[e]	NH2b	Engine control closing	RP260-1001
118[a]	NH3a	Engine control opening	Flange
119[e]	NH3b	Engine control opening	RP260-1001
120[c]	NH5a	Common hydraulic return	RP260-1001
121	NH5b	Common hydraulic return	RP260-1001
122	NH5c	Common hydraulic return	Flange
123	KF7a-1	Fuel pump inlet No. 1	RP260-1001
124[a]	KF6c-2	Fuel pump inlet No. 2	Flange
125	KF6d-2	Fuel pump inlet No. 2	RP260-1001
126[d]	KF7a-2	Fuel pump inlet No. 2	RP260-1001
127	GG1d	Gas generator chamber	Flange
128	GF2a	Gas generator fuel injection	RP260-1001
129	GF2b	Gas generator fuel injection	RP260-1001
130	GO2a	Gas generator oxidizer injection	RP260-1001
131[b]	GO2b	Gas generator oxidizer injection	RP260-1001
131A	GO5	Gas generator oxidizer inlet	RP260-1001
132	GO1a	Gas generator valve inlet	RP260-1001
133	GO1b	Gas generator valve inlet	RP260-1001
134	NHO	Ground hydraulic supply	RP260-1001
135[b]	HO5	Heat exchanger GOX outlet	RP260-1001
136	HH2c	Heat exchanger helium inlet	RP260-1001
137	LB1a	Oxidizer pump bearing jet	Flange
138	LB1b	Oxidizer pump bearing jet	RP260-1001
139[d]	PO2c-1	Oxidizer pump discharge No. 1	RP260-1001
140	PO2d-1	Oxidizer pump discharge No. 1	RP260-1001
141	PO2c-2	Oxidizer pump discharge No. 2	RP260-1001
142[a]	PO7a	Oxidizer pump seal cavity	Flange
143	PO7b	Oxidizer pump seal cavity	RP260-1001
144	NH1a	Control system supply	AND10050-4
145	NH1b	Control system supply	AND10050-4
146	NH8	Control system override	AND10050-4

(a) Engines not incorporating MD96 or MD97 change
(b) Engines not incorporating MD140 change
(c) Engines not incorporating MD177 change
(d) Engines not incorporating MD146 change
(e) Engines not incorporating MD141 change

Figure 2-24. Instrumentation Tap Locations (Sheet 7 of 8)

Item No.	Tap No.	Accelerometer Measurement Description	Direction of Sensitivity (Axis)	Item No.	Tap No.	Accelerometer Measurement Description	Direction of Sensitivity (Axis)
201	CZA1-Y	Oxidizer dome position 1	Y	216	PZA6-Z	Elbow to inlet flange fuel pump No. 2	Z
202	CZA2-Y	Oxidizer dome position 2	Y	217	PZA7-X	Elbow to inlet flange fuel pump No. 2	X
203	CZA3-Y	Oxidizer dome position 3	Y	218	PZA8-Y	Boss of fuel pump housing	Y
204	CZA4-Y	Oxidizer dome position 4	Y	219	PZA9-Z	Boss of fuel pump housing	Z
205	CZA5-Y	Oxidizer dome position 5	Y	220	PZA10-Y	Boss of fuel pump housing	X
206	CZA6-Y	Oxidizer dome position 6	Y	221	MZA1-X	Interface panel support No. 1 side	Y
207	CZA7-X	Oxidizer dome position 7	X	222	MZA2-Z	Interface panel support No. 1 side	Z
208	CZA8-Y	Oxidizer dome position 8	Y	223	MZA3-X	Interface panel support No. 1 side	X
209	CZA9-Y	Oxidizer dome position 9	Y	225	MZA5-Z	Interface panel support No. 2 side	Z
210	CZA10-Y	Oxidizer dome position 10	Y				
211	PZA1-Y	Oxidizer pump inlet flange	Y				
212	PZA2-Y	Elbow to inlet flange fuel pump No. 1	Y				
213	PZA3-Z	Elbow to inlet flange fuel pump No. 1	Z				
214	PZA4-X	Elbow to inlet flange fuel pump No. 1	X				
215	PZA5-Y	Elbow to inlet flange fuel pump No. 2	Y				

Figure 2-24. Instrumentation Tap Locations (Sheet 8 of 8)

2-50. JOINT AND SEAL DATA.

2-51. SEAL DESCRIPTION.

2-52. Eight types of seals are used in the engine systems. Typical use of the more uncommon seals are shown in figure 2-25. The following paragraphs describe the various types of seals and their applications.

2-53. NAFLEX SEALS. The Naflex seal (see figure 2-25) is a pressure-actuated, U-shaped seal with the slot opening radially inward. The legs of the U act as springs to preload the seal leg tip at the flange. The leg tip is covered with a thin teflon film for cryogenic applications or a soft copper or silver plating for high-temperature applications. The film or plating deforms plastically at ambient temperatures to conform to flange surface irregularities. Loading of the seal tips by the spring legs effects a seal at low pressures and also compensates for flange separation due to increased pressure and differences in material shrinkage caused by temperature changes. On double Naflex seals, the heel of the seal is also teflon-film-coated or copper- or silver-plated. The cavities on either side of the heel, formed by the two seals, are connected by small diameter holes. The cavities are then ducted through the flange area to provide leakage monitoring capability for the seal.

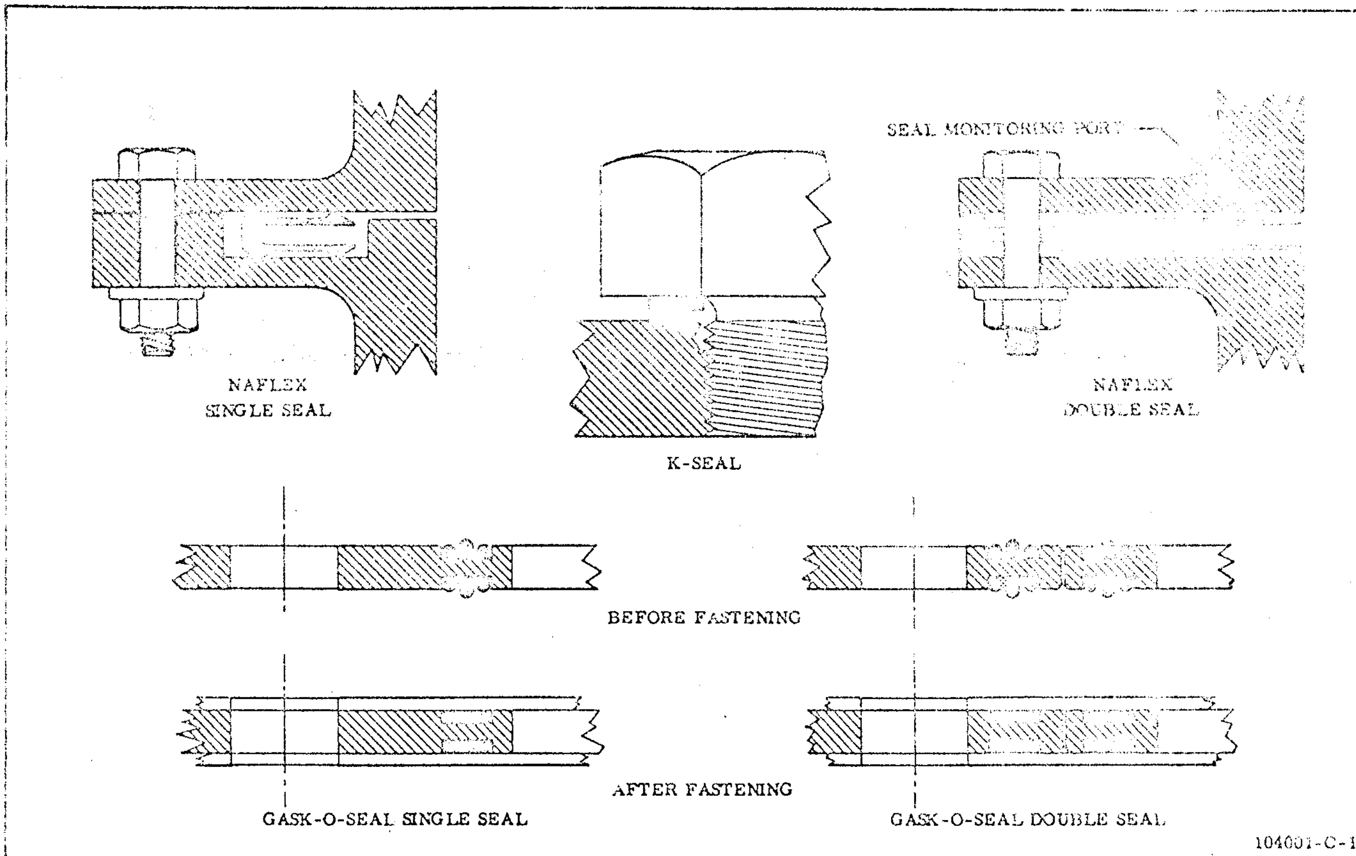


Figure 2-25. Seal Application (Typical)

2-54. GASK-O-SEALS. The gask-o-seal (see figure 2-25) is a metal plate with a rubber seal molded into a groove in the plate. Sealing is accomplished by initial compression of the rubber between mating flanges and extrusion of the rubber by the pressurized fluid. The double gask-o-seal consists of a metal plate with rubber seals molded into two grooves in the plate. The cavities on either side of the plate, formed by the two rubber seals, are connected by small diameter holes. The cavities are then ducted through the flange area to provide leakage monitoring capability of the seal.

2-55. K-SEALS. The K-seal (see figure 2-25) is a metal seal coated with teflon for cryogenic applications and silver or gold plating for high-temperature applications. This seal is used only on small threaded joints where flange separation will not take place since the leg movement of the K-seal is limited.

2-56. O-RING SEALS. The O-ring seal is an elastomeric rubber seal used for static and dynamic joints in fuel and hydraulic applications. The seal material is Buna N except where the seal will be exposed to trichloroethylene; then the material is Viton A. Sealing is effected by compressing the seal between mating parts on installation; the pressurized fluid also extrudes the seal against the mating parts.

2-57. ASBESTOS SEALS. Two types of asbestos seals are used for hot-gas applications at the nozzle extension joint. The thermocore seal, consisting of two wrappings of 1/8-inch asbestos rope, is installed in the nozzle extension flange and depends on a high uniform flange preload to provide a good seal. On engines incorporating MD135 change, an asbestos gasket (tadpole) seal replaces the thermocore seal because of its greater resiliency. This seal consists of two wire-mesh rings covered with asbestos cloth. During nozzle extension installation, the large ring is compressed in the flange groove, and the small ring between the mating flanges.

2-58. COPPER CRUSH SEALS. The copper crush seal is a soft-metal-type washer. Joints using this type of seal have machined sharp circumferential ridges to obtain increased unit loading of the seal. Sealing is achieved by preloading the seal between two flanges. This type of seal is used for high-temperature applications.

2-59. FLARED SEALS. The flared seal consists of a machined, female, flared fitting welded to a tube end, a coupling nut on the tube, and a mating male connector. The coupling nut mates with an external shoulder on the flared fitting. Sealing is achieved between the nose of the male connector and the machined flare as the connector nut is tightened on the male connector.

2-60. SPIRAL-WOUND GASKETS AND METAL O-RINGS. The spiral-wound (spirotallic) gasket consists of a spirally wound steel ribbon, of chevron cross-sectional shape, with copper or teflon filler between turns. The seal is used in the thrust chamber oxidizer dome-to-injector joint. The metal O-ring seal is used in the thrust chamber body-to-injector joint and provides a seal between fuel and hot gas.

2-61. JOINT AND SEAL IDENTIFICATION.

2-62. The locations of system joints are shown in figures 2-26 and 2-27. (Refer to R-3896-3 for removal and installation torque values and R-3896-4 when ordering seals.) The schematics are zoned and each joint is assigned a code number to aid in identification and cross-reference between each schematic and its legend. The code designation identifies the type of fluid used at a specific joint, location of the joint, and if the joint seal leakage can be monitored. Fluid identifications are as follows: O, oxidizer; F, fuel; HF, hydraulic fuel; HG, hot gas; H, helium; and N, nitrogen. For joint location, D designates drain joints. Leakage monitoring ports are indicated by an M. The seal type and material codes used in the legends are as follows:

Type Identification

Type	Code
Crush seal	CR
Flared fitting	F
Gask-o-seal	GO
K-seal	KB
Naflex seal	NA
O-ring seal	OR
Spirotallic seal	SP
Thermocore seal	T
Tadpole seal	TP

Material Identification

Material	Code
Aluminum	AL
Asbestos	A
Asbestos - rubber	AR
Asbestos - inconel	AI
Buna N	BN
Copper	C
Copper-plated nickel base	CN
Silver-plated nickel base	SN
Stainless steel	S
Copper-plated stainless steel	CS
Gold-plated stainless steel	GS
Silver-plated stainless steel	SS
Teflon-fill stainless steel	STF
Teflon-coated steel	TS
Viton A	VA

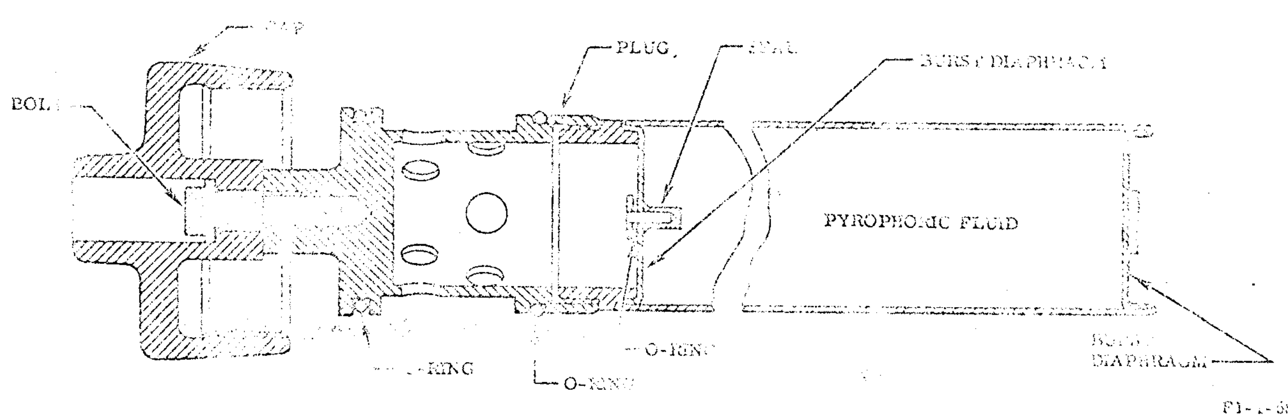


Figure 1-25. Hypergol Igniter

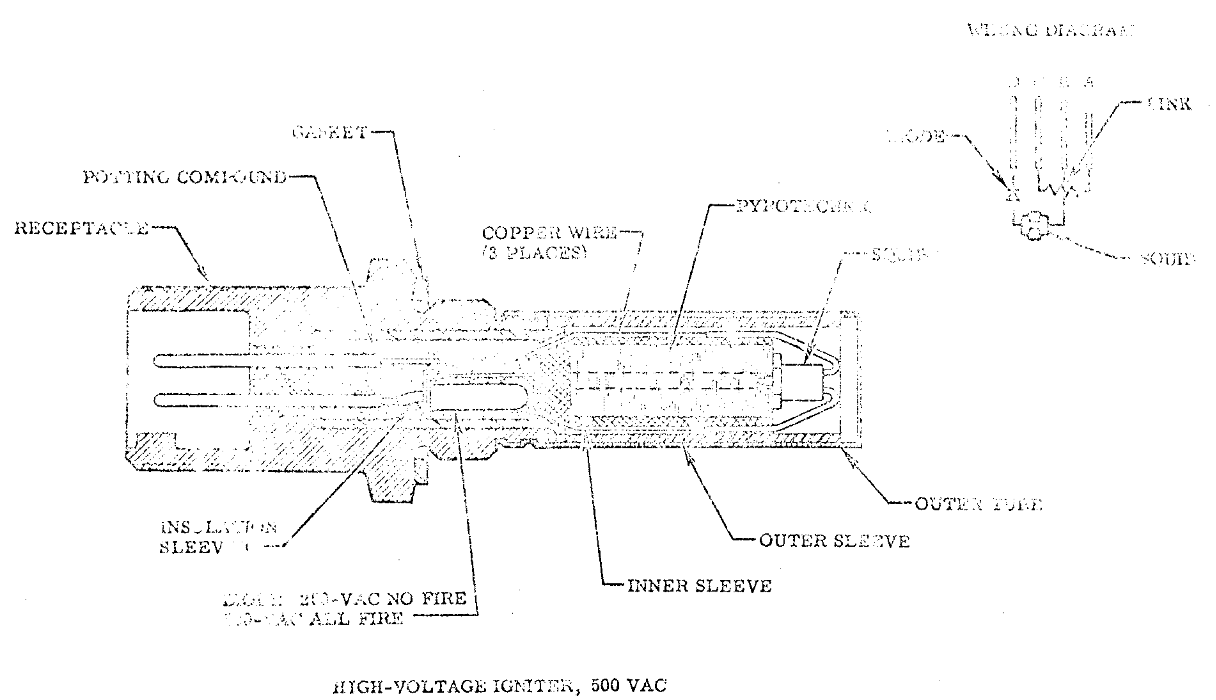


Figure 1-26. Pyrotechnic Igniter

gas in the nozzle extension. Two igniters are installed in igniter bosses of the gas generator combustor inlet flange, and two igniters are installed in bosses in the nozzle extension near the 11:1 expansion ratio area. The igniter external structure consists of a metal tube crimped and soldered at one end into a receptacle with four electrical contact pins. The opposite end of the tube is sealed with a disc of silver alloy foil. Internally, the igniter has two plastic sleeves, a dual-element squib assembly, a main pyrotechnic charge, a diode, and the wire required to connect the two igniter circuits to the four receptacle pins. When an electrical stimulus of 500 vac is impressed on the igniter circuit (BD), the diode is triggered allowing a nominal 4.5 amperes of current to flow and ignite the squib. The flame and hot particles from the squib ignite the main pyrotechnic charge. The burning of the main charge severs the link wire imbedded in the charge within 200-800 milliseconds and continues burning for 6.5 to 9.5 seconds. Severing of the igniter link wire provides a positive signal to the engine electrical control system that the igniter has functioned satisfactorily. When 250 vac or less is impressed on the squib circuit, the diode prevents current flow and the igniter will not fire.

1-61. GAS GENERATING SYSTEM DESCRIPTION.

1-62. The gas generating system provides the internal power required to operate the engine. Utilizing tank-head energy from the vehicle, the gas generating system develops sufficient power to start the engine and changes to its rated power level of operation by using a portion of its own output (bootstrapping). The internal power is generated by tapping propellants from the high-pressure ducts and directing them to the gas generator where hot gas is produced to power the turbopump. After impacting the two-stage turbine, the gas is further utilized by a heat exchanger where additional heat is extracted to condition the gases used for vehicle tank pressurization. The now relatively cool gas generator exhaust gas is directed into the lower section of the thrust chamber to provide film cooling of the double-wall portion of the nozzle. Orifices in the propellant ducts to the gas generator control the power level of the system to provide a constant mass flowrate to the thrust chamber, thereby insuring a constant thrust output. Gas generator leading particulars are listed in figure 1-27.

1-63. GAS GENERATOR DESCRIPTION.

1-64. The gas generator (figure 1-28) is within a basic envelope 18 by 24 by 28 inches and weighs approximately 220 pounds. The gas generator consists of a dual ball valve, an injector fuel inlet housing tee, an integral oxidizer dome and injector, and a combustor. Six types of seals are used in the gas generator: silver-plated stainless-steel Naflex and K-seals and copper crush washers for hot-gas applications, Teflon-coated steel K-seals for cryogenic applications, and Buna-N O-rings for fuel applications.

Combustor temperature	1,453° F
Injector end pressure	980 psia
Oxidizer flowrate	49 lb/sec
Fuel flowrate	118 lb/sec
Mixture ratio	0.416:1.0
Combustor pressure drop	33.5 psia
Injector pressure drop (oxidizer)	250 psia
Injector pressure drop (fuel)	145 psia
Gas generator ball valve pressure drop (oxidizer)	55 psia
Gas generator ball valve pressure drop (fuel)	200 psia
Orifice pressure drop (oxidizer)	261 psia
Orifice pressure drop (fuel)	375 psia
Line pressure drop (oxidizer)	76 psia
Line pressure drop (fuel)	43 psia
Gas generator ball valve open time (switch to switch)	170 msec
Gas generator ball valve closed (switch to switch)	90 msec

Figure 1-27. Gas Generator Leading Particulars (Engines Incorporating MD128 or MD174 Change)

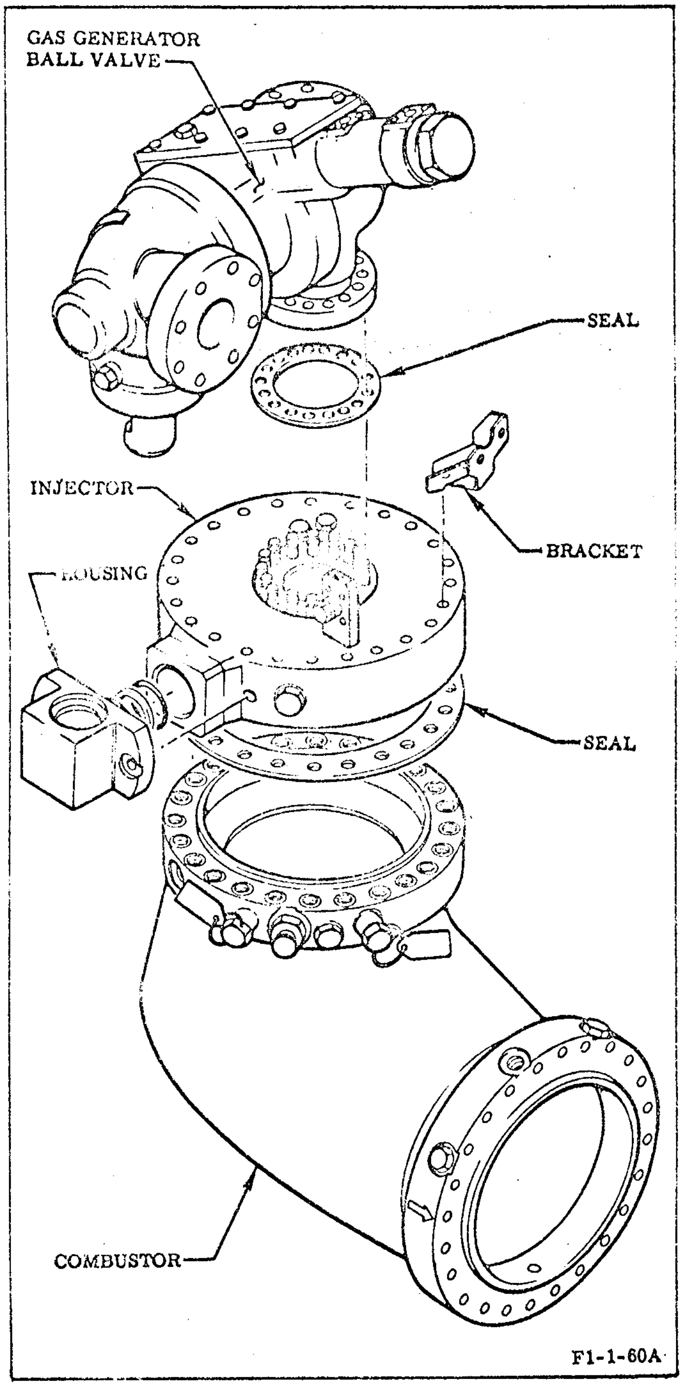


Figure 1-28. Gas Generator

1-65. GAS GENERATOR BALL VALVE DESCRIPTION. The gas generator ball valve (figure 1-29) is a hydraulically operated valve incorporating two hollow balls connected to a single actuator for directing propellants into the gas generator injector. The balls are shells on shafts, each shell having an inlet and outlet flow passage. The inlet and outlet flow passages are located diametrically opposite each other in the oxidizer ball and 150 degrees apart in the fuel ball. A tube is welded between the inlet and outlet passages in the fuel ball to reduce flow resistance. Both balls seat against bellows-type seals. The fuel bellows seal incorporates a deflection elbow for the fuel outlet that is contoured to reduce pressure drop in the gas generator fuel system. Both ball shafts rotate on roller bearings, and each ball also rotates against the actuator housing on roller bearings and races.

1-66. The gas generator ball valve contains a linear-motion position switch and an integral electrical connector, mounted in the valve cover. The housing cover contains tapped holes for installation of Stage Contractor thermocouples. The cover is used to seal the switch compartment. The ball valve oxidizer outlet attaches directly to the gas generator injector oxidizer inlet. The gas generator fuel inlet housing tee connects the ball valve outlet to the injector fuel inlet. The gas generator ball valve opening is directed by sequence valves on the oxidizer valves. Hydraulic fluid recirculates through a warmant passage in the fuel ball housing, preventing the fuel in the fuel ball housing from freezing, and through a passage in the piston between the opening port and the closing port, preventing air entrapment and hydraulic fluid freezing. Four types of seals are used in the gas generator ball valve: machined KEL-F seals, KEL-F lip seals, Buna-N O-rings, and a Teflon-coated steel Naflex seal.

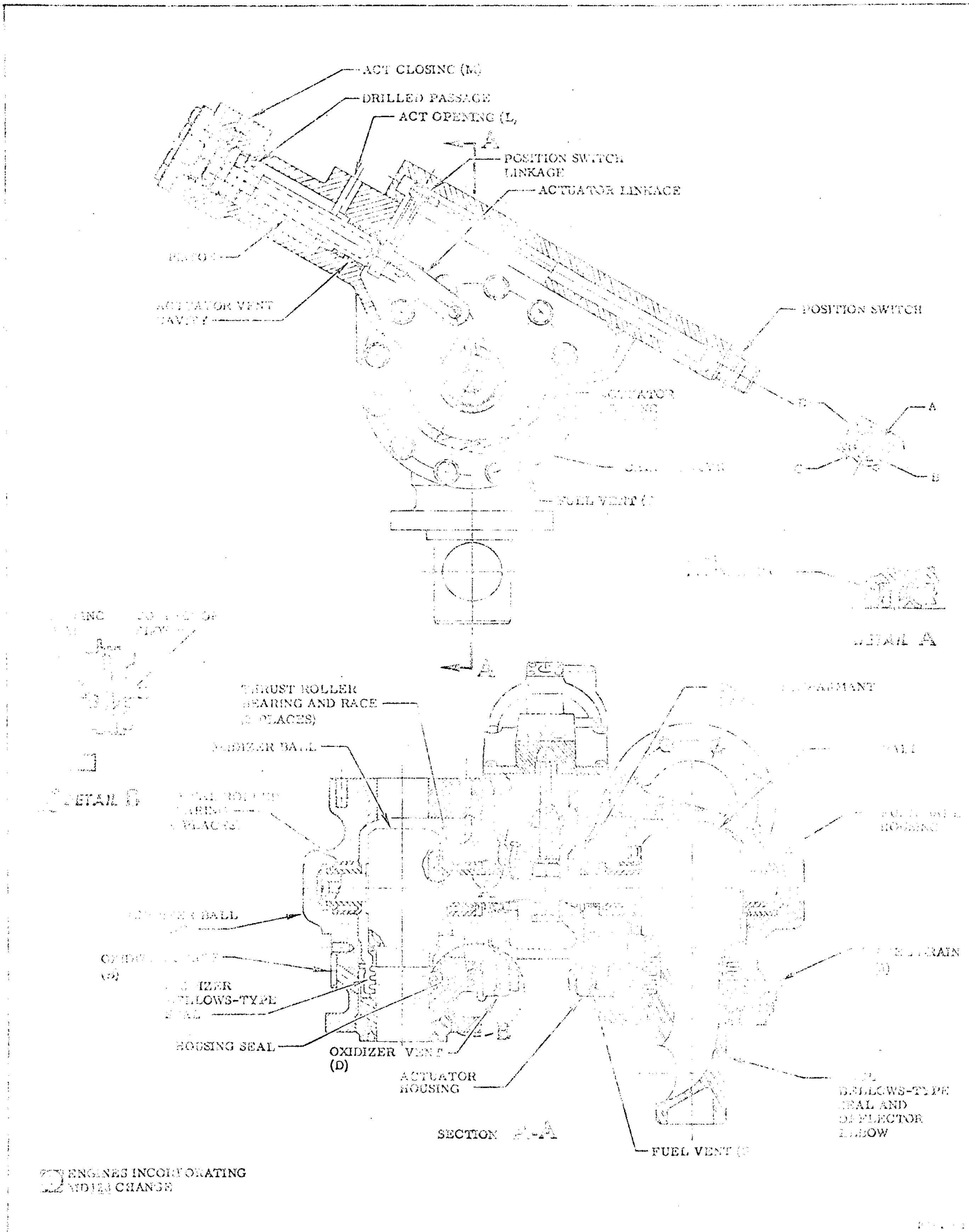


Figure 1-25. Gas Generator Ball Valve

1-67. GAS GENERATOR INJECTOR DESCRIPTION. The gas generator injector (figure 1-30) is a flat-faced, multi-orificed-type injector incorporating a dome, a plate, a ring manifold, five oxidizer rings, five fuel rings, and a fuel disk. The injector is mounted on the combustor, and the gas generator ball valve and the gas generator fuel inlet housing tee are mounted on the injector. The injector directs fuel and oxidizer into the gas generator combustor. Fuel enters the injector through the gas generator fuel inlet housing tee from the gas generator ball valve. The fuel is directed through radial passages in the plate and injected into the combustor through orifices in the five fuel rings and the fuel disk. Oxidizer enters the injector through the oxidizer inlet manifold from the gas generator ball valve. The oxidizer is directed from the oxidizer manifold through internal passages in the plate and is injected into the combustor through the orifices in the five oxidizer rings. The injector uses a double-orificed pattern in which the fuel and oxidizer rings are drilled in a pattern and angle so that the stream from one oxidizer orifice will impinge upon the stream from another oxidizer orifice, and the stream from a fuel orifice will impinge upon the stream from another fuel orifice. Orifices in the outer fuel ring also provide a cooling film of fuel for the combustor choke ring wall.

1-68. GAS GENERATOR COMBUSTOR DESCRIPTION. The gas generator combustor (figure 1-30) is a welded single-walled manifold connecting the gas generator injector and the turbine inlet. The combustor contains a chamber for burning propellants and for exhausting the gases from the burning propellants into the turbopump turbine manifold. The combustor is thermally insulated by a sheet metal shell that bolts around the combustor body. The inlet flange is the attach point for the injector and dome assembly and incorporates a 45-degree lip section that deflects the flame pattern to the bottom section of the combustor. Also incorporated in the inlet flange are the two bosses (45 degrees apart) for pyrotechnic igniter installation and two ports (150 degrees apart) to monitor gas pressure at this point. A port to measure or vent seal leakage past the seal between the injector and combustor is also located on the combustor inlet flange. The combustor outlet flange, which is the attach point for the turbine manifold, incorporates two ports (90 degrees apart) to monitor gas pressure and one port to vent or measure seal leakage past the seal at this interface. Combustor wall temperatures are held to safe operating limits by the combination of film coolant provided by the outer fuel ring of the injector, and the fuel-rich mixture ratio with which the gas generator operates.

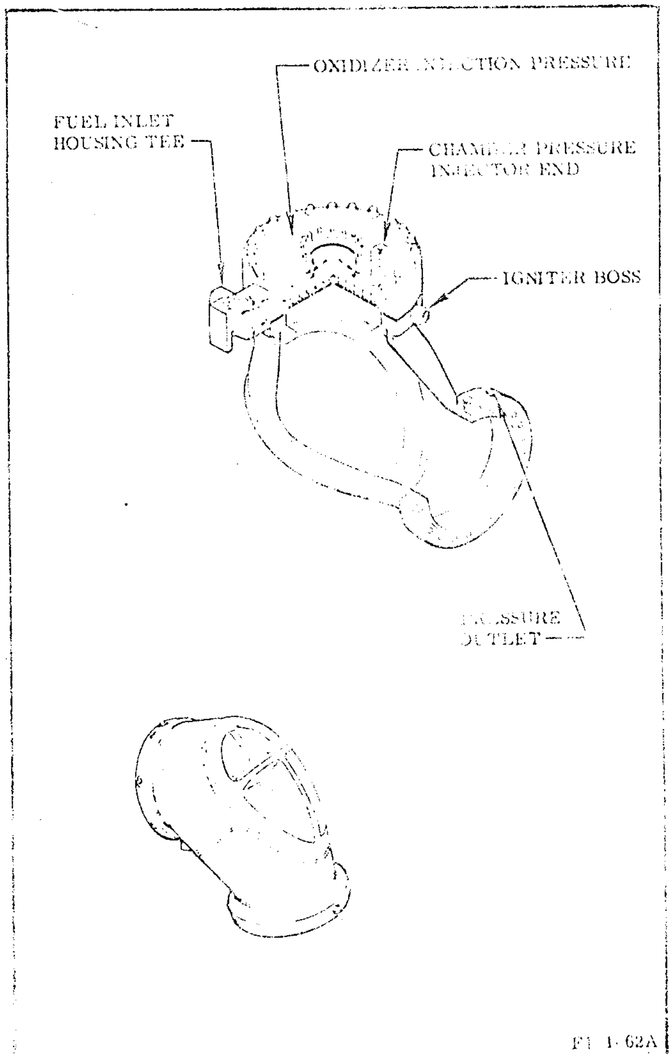


Figure 1-30. Gas Generator Injector and Combustor

1-69. GAS GENERATOR OXIDIZER DUCT DESCRIPTION. The gas generator oxidizer duct contains and distributes the oxidizer from the No. 2 turbopump oxidizer outlet duct to the gas generator ball valve oxidizer inlet. The gas generator oxidizer duct is a two-piece, 1-1/2 inch ID duct incorporating three bellows-connected gimbal joints to allow flexing to accommodate installation tolerances and thermal expansion or contraction of the duct. The gas generator oxidizer duct incorporates two orifices for oxidizer flowrate calibration. One orifice is installed at the interface of the gas generator oxidizer duct and the No. 2 turbopump oxidizer outlet duct,and the other orifice is installed at the interface of the two gas generator oxidizer duct sections. Both orifices are sized at engine acceptance test. A fluid scoop, which extends into the fluid stream of the No. 2 turbopump oxidizer outlet duct, is installed at the interface of the gas generator oxidizer duct and the No. 2 turbopump oxidizer outlet duct.

1-70. GAS GENERATOR FUEL DUCT DESCRIPTION. The gas generator fuel duct contains and distributes the fuel from the No. 2 turbopump fuel outlet duct to the gas generator ball valve fuel inlet. The gas generator fuel duct is a one-piece, 2-1/4 inch ID duct incorporating three bellows-connected gimbal joints to allow flexing to accommodate installation tolerances, thermal expansion, and contraction of the duct. The gas generator fuel duct incorporates an orifice for fuel flowrate calibration. The orifice is installed at the interface of the gas generator fuel duct and the No. 2 turbopump fuel outlet duct. The orifice is sized during the engine acceptance test. A flow deflector is installed at the interface of the gas generator fuel duct and the gas generator ball valve fuel inlet.

1-71. HEAT EXCHANGER DESCRIPTION.

1-72. The heat exchanger (figure 1-31) is within a basic envelope 43 inches in diameter and 58 inches in length, with the diameter varying from 40 inches at the turbine outlet to 24 inches at the turbine exhaust manifold. Hot gases from the turbine are directed to the heat exchanger where a portion of the heat is transferred to the oxidizer and helium coils. In the heat transfer, oxidizer in the coils is converted to GOX for vehicle oxidizer tank pressurization, and the chilled helium in the coils is expanded for vehicle fuel tank pressurization. The upper section of the heat exchanger encloses the helium coils and mounting flanges for the helium and oxidizer supply and return lines. Each mounting flange is provided with ports to measure seal leakage. The supply ports incorporate orifices to control the flow of oxidizer or helium through the coils. The lower section of the heat exchanger encloses the oxidizer coils and contains a bellows assembly to compensate for thermal expansion during engine operation. Tubular structural members, clamped to the coils and welded to brackets incorporated in the heat exchanger body, secure and restrain the oxidizer coils. Heat exchanger connections at the turbine outlet manifold and the thrust chamber exhaust manifold are sealed by pressure-actuated Naflex seals.

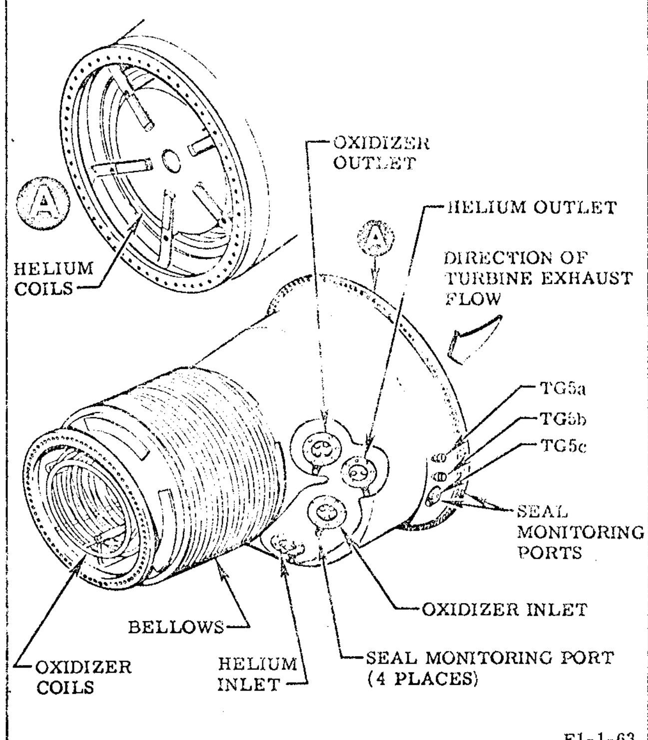


Figure 1-31. Heat Exchanger

1-73. ENGINE CONTROL SYSTEM DESCRIPTION.

1-74. The engine control system regulates the total engine operation. To provide this regulation, the engine control system directs, governs, and sequences the activity of engine propellant valves during the start, transition, mainstage, and cutoff phases of engine operation. Major components of the engine control system are the engine control valve, redundant shutdown valve, checkout valve, and hypergol manifold assembly. Orifices in the engine control system control propellant valves timing.

1-75. ENGINE CONTROL VALVE DESCRIPTION.

1-76. The engine control valve (figure 1-32) directs hydraulic fluid to open and close the propellant valves and the gas generator ball valve. The valve is electrically controlled and hydraulically actuated, with an internal hydraulic lockup that maintains actuation when the start signal is removed. The valve includes an override piston to deactuate the valve in case of stop solenoid failure. The assembly consists of a control section and a filter manifold section.

1-77. The control section consists of two solenoid-operated pilot (start and stop) valves, two slaved poppet valves, a matched selector spool and sleeve, a stop actuator, an override piston, and a valve body. The solenoid-operated pilot valves are identical except the start solenoid electrical connector has two pins and the stop solenoid has three pins to prevent improper connection. To ensure that the engine cannot be started with the stop solenoid disconnected, the negative lead of the start solenoid is wired in series with the negative lead of the stop solenoid. Each solenoid valve consists of a coil, a double-acting poppet (the armature), and two poppet seats (upstream and downstream). The coil is energized by 24-30 vdc. The poppet is spring loaded against the downstream seat. Each solenoid valve is protected by a 10-micron filter at its inlet passage. A passage in the control valve body directs fluid to a passage that directs fluid to the poppet cavity. Two passages permit fluid flow from the cavity to the slaved pilot valve cylinder when the poppet is deenergized. The downstream seat forms the base of the valve assembly and contains a passage that is closed by the deenergized poppet and opened when the poppet is energized.

1-78. Two slaved pilot valves, each slaved to its respective solenoid pilot valve, direct fluid to shuttle the selector spool. Each slaved pilot valve consists of a poppet, two identical poppet seats, a piston, a cylinder, and a spring. The poppet is a pressure-actuated disc that free-floats between the two poppet seats. Both faces of the poppet are finished to provide a metal-to-metal seal with the poppet seats. The poppet seats, separated by a spacer, are installed face-to-face on both sides of the poppet. At start, momentary off-seating of the poppet from the normal position allows hydraulic pressure to shuttle the selector spool to open. The cylinder houses the piston and spring and is ported to admit hydraulic pressure to the spring cavity when the solenoid pilot valve is deenergized. When the start solenoid is energized, the piston is momentarily actuated through the force transmitted to the piston shaft by the poppet.

1-79. The selector valve is a matched spool and sleeve. The spool, floating inside the sleeve, is a hollow, closed-end cylinder with three ports and two sealing lands. The spool is actuated from its normal spring-loaded position (closed) by fluid pressure by the momentary actuation of the slaved pilot valve at start. Once actuated, the spool is hydraulically locked by fluid pressure from the open port. The sleeve

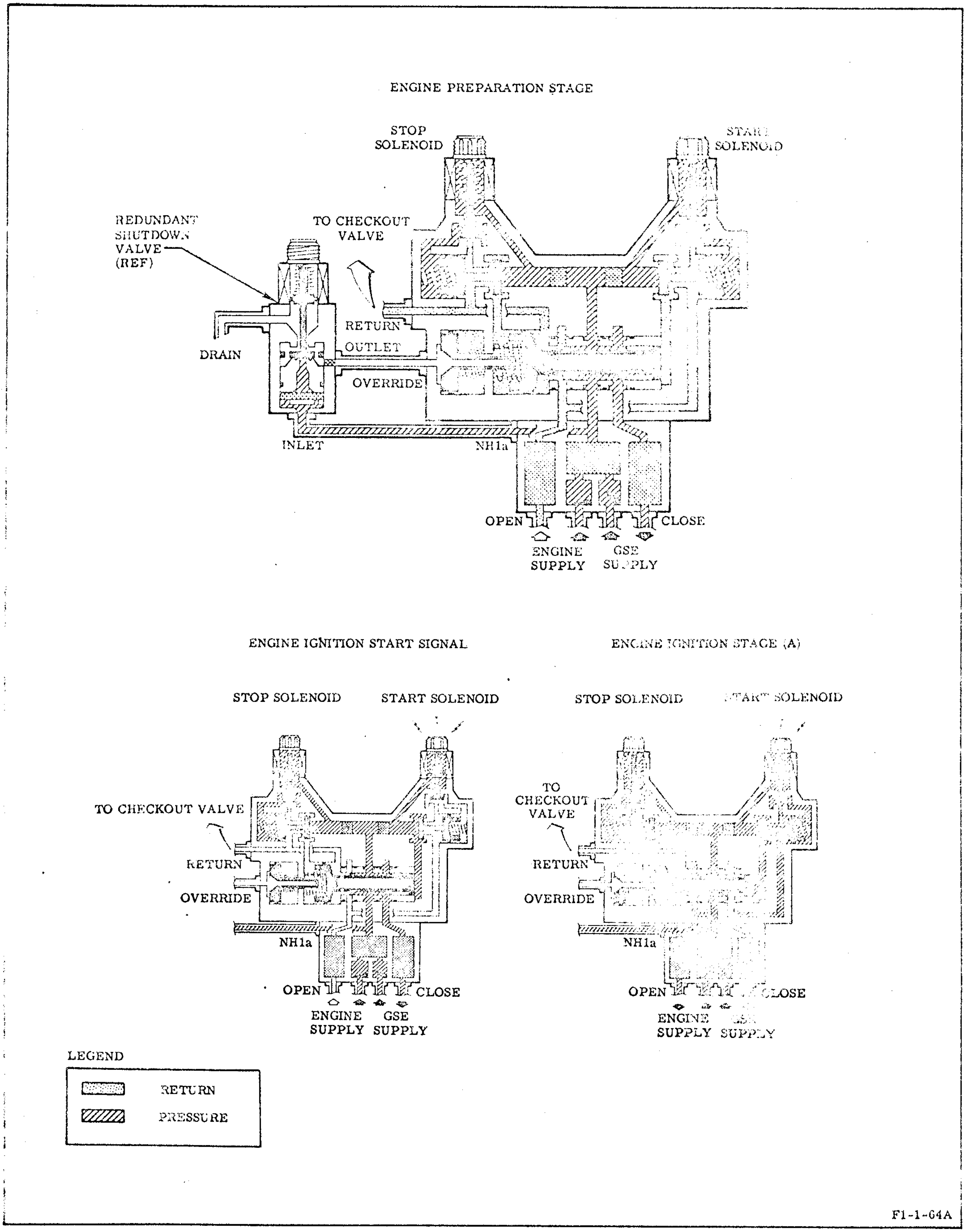


Figure 1-32. Engine Control Valve and Redundant Shutdown Valve Schematic (Sheet 1 of 2)

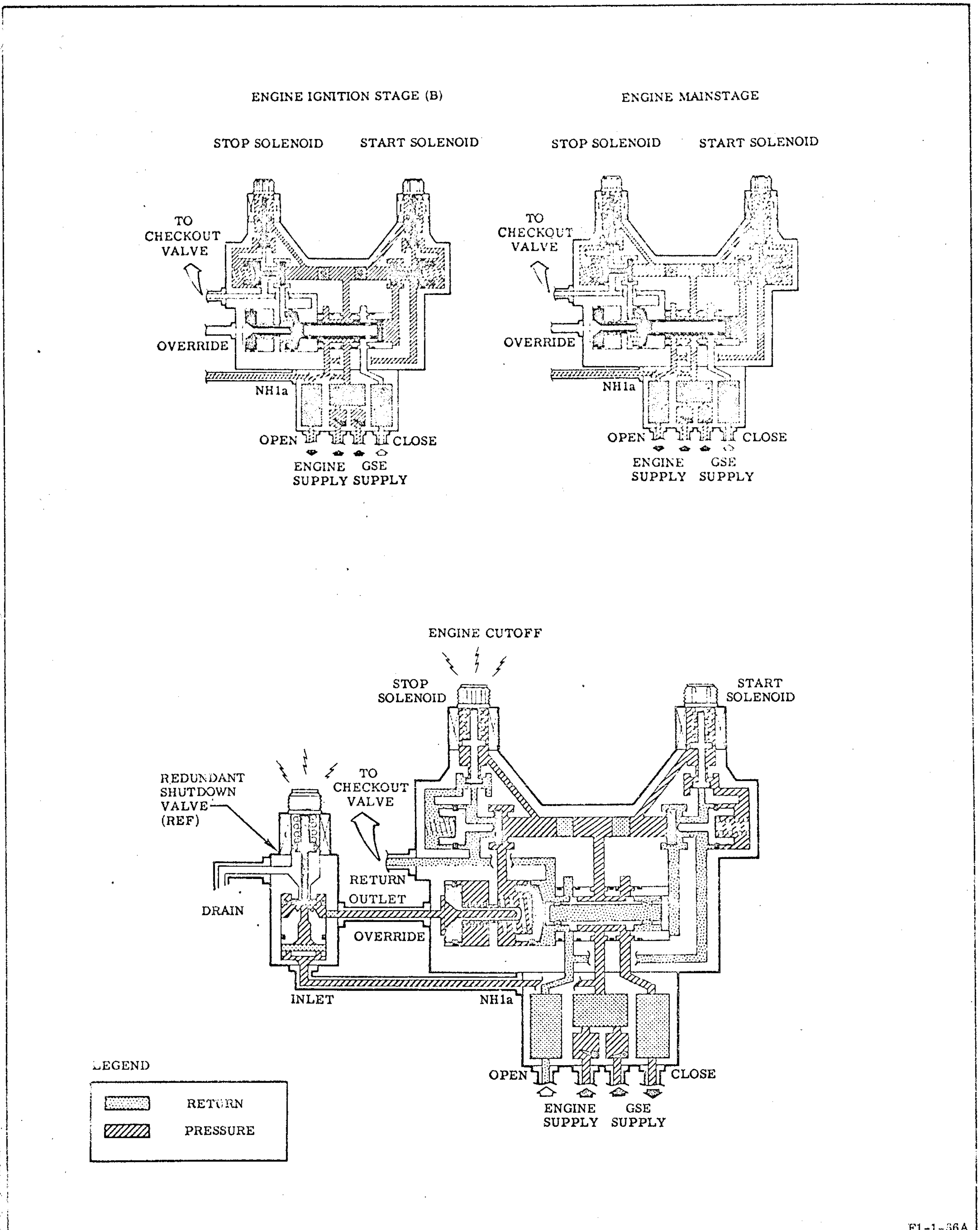


Figure 1-32. Engine Control Valve and Redundant Shutdown Valve Schematic (Sheet 2 of 2)

has three ports that aline with three annular passages in the selector valve cavity. Four O-rings with Teflon backup rings prevent leakage between the annular passages. A threaded retaining cap holds the selector valve in its cavity and provides a mechanical stop for the spool.

1-80. The stop actuator is a spring-loaded, hydraulically actuated piston that positions the selector spool to the closed position. The actuator is normally controlled by the stop slaved pilot valve but can be directly actuated by the override piston in case of stop valve failure. Four holes admit control fluid into the spring cavity from an annular passage supplied from the stop slaved pilot valve. The override piston is hydraulically actuated and mechanically coupled to the stop actuator. The piston is used to position the selector spool in case of stop valve failure. An external pressure source is required to actuate the piston, which mechanically positions the selector spool to the closed position. The piston is held deactuated against a stop by a coil spring. The stop retains the override piston in its cavity and incorporates the override pressure inlet port. The control valve body houses the operational units and bolts to the filter manifold assembly. The interface of valve body and filter assembly is sealed by a seal plate.

1-81. The filter manifold is the supply filtration and distribution point for all control system fluid. The filter manifold consists of two swing-gate check valves, three filters, and a manifold body. The check valves are flange mounted back-to-back in a common supply cavity. One check valve covers the GSE SUPPLY fluid inlet port, and the other check valve covers the ENG SUPPLY fluid inlet port. Three 25-micron wire-mesh filters are installed in the manifold assembly. One filter is in the supply system and one each in the opening and closing passages. The manifold body houses the filters and is bolted to the control valve body. Two threaded ports in the ENGINE/GSE filter supply cavity provide pressure for instrumentation and for the emergency override system. Passages connect the closed, open, and supply filter cavities to corresponding ports of the control section. Three types of seals are used in the engine control valve: Viton-A O-rings for plug and bleeder seals, a Viton-A Gask-O-Seal at the manifold-to-solenoid-valves joint, and Buna-N O-rings for all other applications.

1-82. REDUNDANT SHUTDOWN VALVE DESCRIPTION.

1-83. The redundant shutdown valve (figure 1-33) is a solenoid-operated, normally closed, three-way valve incorporating two 10-micron filters (one disk shaped, the other cylindrical), fixed inlet and vent seats, and a floating poppet that is spring loaded to the closed position against the inlet seat. The function of the valve is to direct hydraulic pressure to the engine control valve override pressure port as a redundant means of effecting engine shutdown in case of failure of the engine control valve stop solenoid, and to provide a drain for the override pressure port during engine checkout and operation. Continuous application of 24-30 vdc is required to keep the valve energized. The energizing signal input is applied simultaneously to the redundant shutdown valve solenoid and the engine control valve stop solenoid at engine cutoff. The redundant shutdown valve body provides an internal threaded DRAIN port and flanged IN and OUT ports. The solenoid electrical connector is a four-pin connector with only three of the pins used. Pin A is used for the positive energizing signal input, pin B for the negative return signal, and pin C for monitoring the signal received at the solenoid. Pins A and D are bussed internally within the connector. The seals used in the redundant shutdown valve are Buna-N O-rings.

1-84. CHECKOUT VALVE DESCRIPTION.

1-85. The checkout valve (figure 1-34) is within a basic envelope 8 by 9 by 14 inches and is located just below the engine control valve on the No. 2 side of the engine thrust chamber jacket. The checkout valve is a motor-driven selector valve that directs engine control return fluid back to the GSE or engine supply source. The checkout valve consists of a ball, a three-port housing, and an actuator. The actuator is a 24-30 vdc reversible motor that incorporates reduction gearing, position switches, and limit switches. The actuator controls the

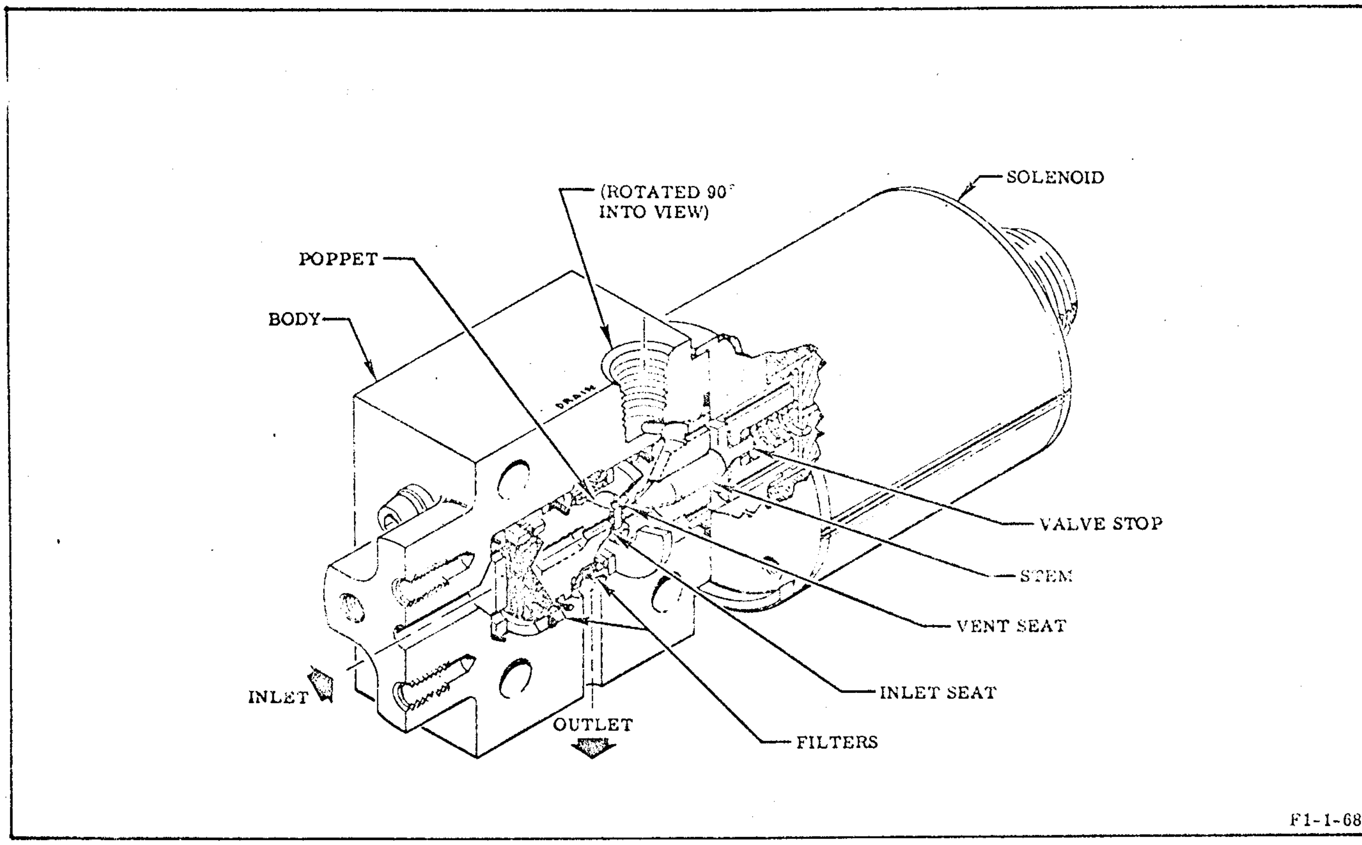


Figure 1-33. Redundant Shutdown Valve

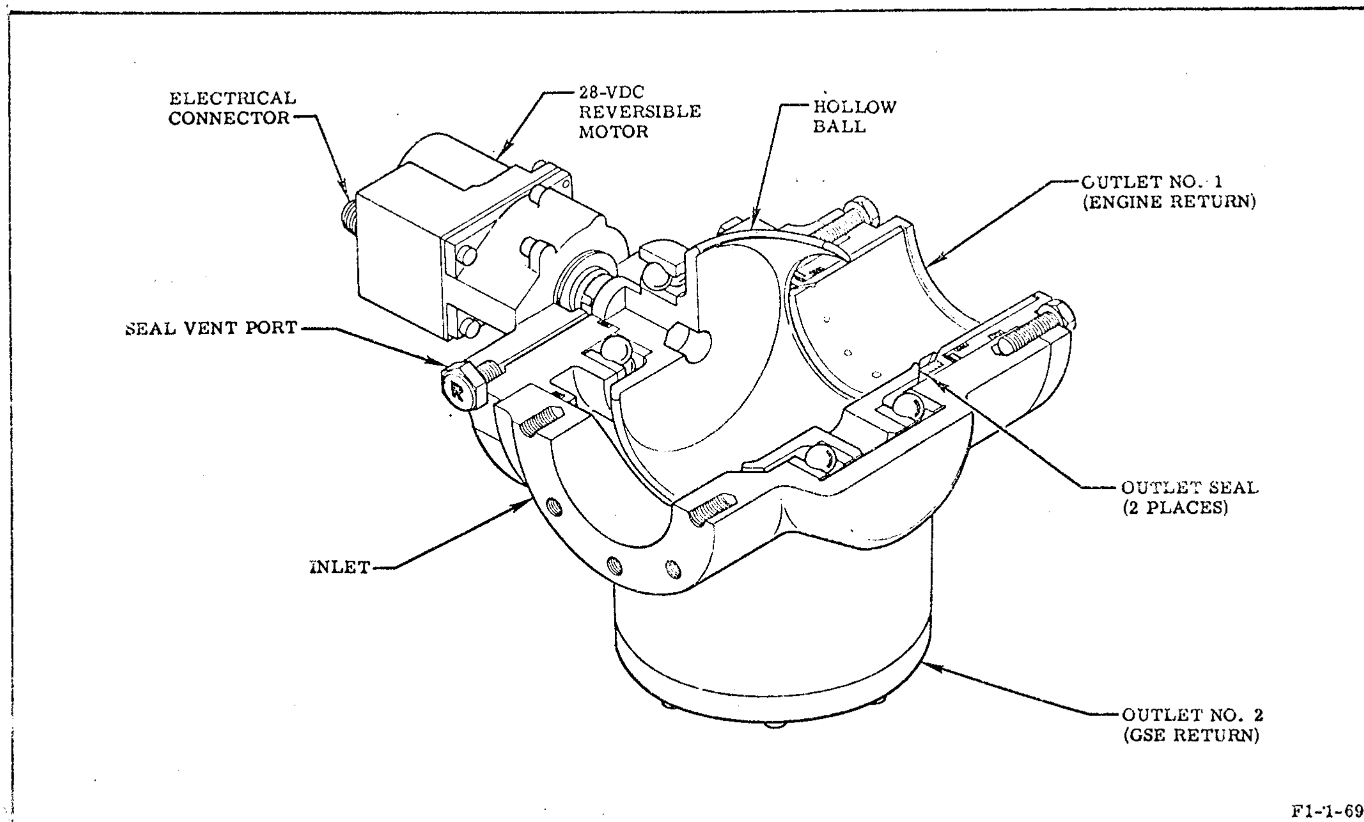


Figure 1-34. Checkout Valve

position of the ball to direct control fluid from the inlet port to one of the outlet ports. During engine checkout or servicing, the checkout valve ball is positioned so that fuel entering the inlet port is directed through the ball and out the GSE return outlet No. 2 port. For engine static firing or flight, the ball is positioned so that fuel entering the inlet port is directed through the ball and out the engine return outlet No. 1 port. Three types of seals are used in the checkout valve: Viton-A O-rings for dynamic applications, Buna-N O-rings for static applications, and machined Teflon seals for the ball seals.

1-86. HYPERGOL MANIFOLD ASSEMBLY DESCRIPTION.

1-87. The hypergol manifold assembly (figure 1-35) sequences engine operation from ignition stage into mainstage. The assembly is attached to a bracket located on the thrust chamber fuel manifold and consists of a hypergol cartridge container, an ignition monitor valve, an igniter fuel valve, and a hypergol installed switch. Only the hypergol cartridge container and hypergol installed switch are replaceable components of the assembly. The hypergol container is a cylindrical manifold into which the hypergol cartridge is installed. The hypergol installed switch is a cam-actuated switch that indicates the installed position of the hypergol cartridge. Hypergol manifold assembly leading particulars are listed in figure 1-36.

1-88. IGNITION MONITOR VALVE DESCRIPTION. The ignition monitor valve (figure 1-37) directs the opening of the fuel valves and permits the fuel valves to open only after satisfactory ignition has been achieved in the thrust chamber. The ignition monitor valve is a spring-loaded, pressure-actuated, fail-to-the-run, three-way valve mounted on the hypergol manifold and actuated by ignition combustion pressure. A dual-faced, spring-loaded poppet directs valve opening pressure to the fuel valves when ignition combustion pressure, acting on a laminated Mylar diaphragm, shuttles the poppet to the valve's open position. Once shuttled, the valve will remain in the open position until engine shutdown due to the differential pressure across the upstream and downstream faces of the poppets. Teflon Viton-A "slipper" seals and Buna-N O-rings are used in dynamic and static seal applications. An internal orifice between the inlet and outlet ports permits fluid recirculation to bleed air from the control fluid. A mechanical lockup, actuated through a cam-rod that is positioned to cam the follower when an unruptured hypergol cartridge is installed, prevents ignition monitor valve actuation until the hypergol cartridge has ruptured. The atmospheric reference port is vented to the fuel overboard drain system.

1-89. IGNITER FUEL VALVE DESCRIPTION. The igniter fuel valve (figure 1-35) is an integral part of the hypergol manifold assembly. The igniter fuel valve is opened by fuel pressure applied to the FUEL INLET port of the hypergol manifold from the No. 1 fuel outlet duct. When the igniter fuel valve is opened, an internal passage in the manifold directs the fuel from the igniter fuel valve to the hypergol container where the fuel first ruptures the hypergol cartridge diaphragms and then follows the hypergolic fluid into the thrust chamber for ignition. A Teflon O-ring in the nose of the poppet seats against a seat machined into the hypergol manifold body. The desired spring loading is obtained by shimming the spring.

1-90. <u>FLIGHT INSTRUMENTATION SYSTEM DESCRIPTION.</u>

1-91. The flight instrumentation system monitors engine performance during checkout, test, and vehicle flight operations. The system consists of pressure transducers, temperature transducers, position indicators, a flow measuring device, power distribution junction boxes, and associated electrical harnesses. The basic flight instrumentation system is composed of a primary and an auxiliary system. The primary instrumentation system includes parameters critical to all engine static firings and subsequent vehicle launches, the auxiliary system is used during research, development, and acceptance test portions of the engine static-test program and initial vehicle flights.

1-92. Eight types of seals are used in the flight instrumentation system installation: asbestos rubber sheet gaskets for electrical connector application; Viton-A O-rings and Gask-O-Seals for fuel applications; copper crush washers, copper-plated nickel-base Naflex seals, and gold-plated steel K-seals for hot-gas applications; and Teflon-coated steel Naflex and K-seals for cryogenic applications. Refer to section II for detailed joint and seal data.

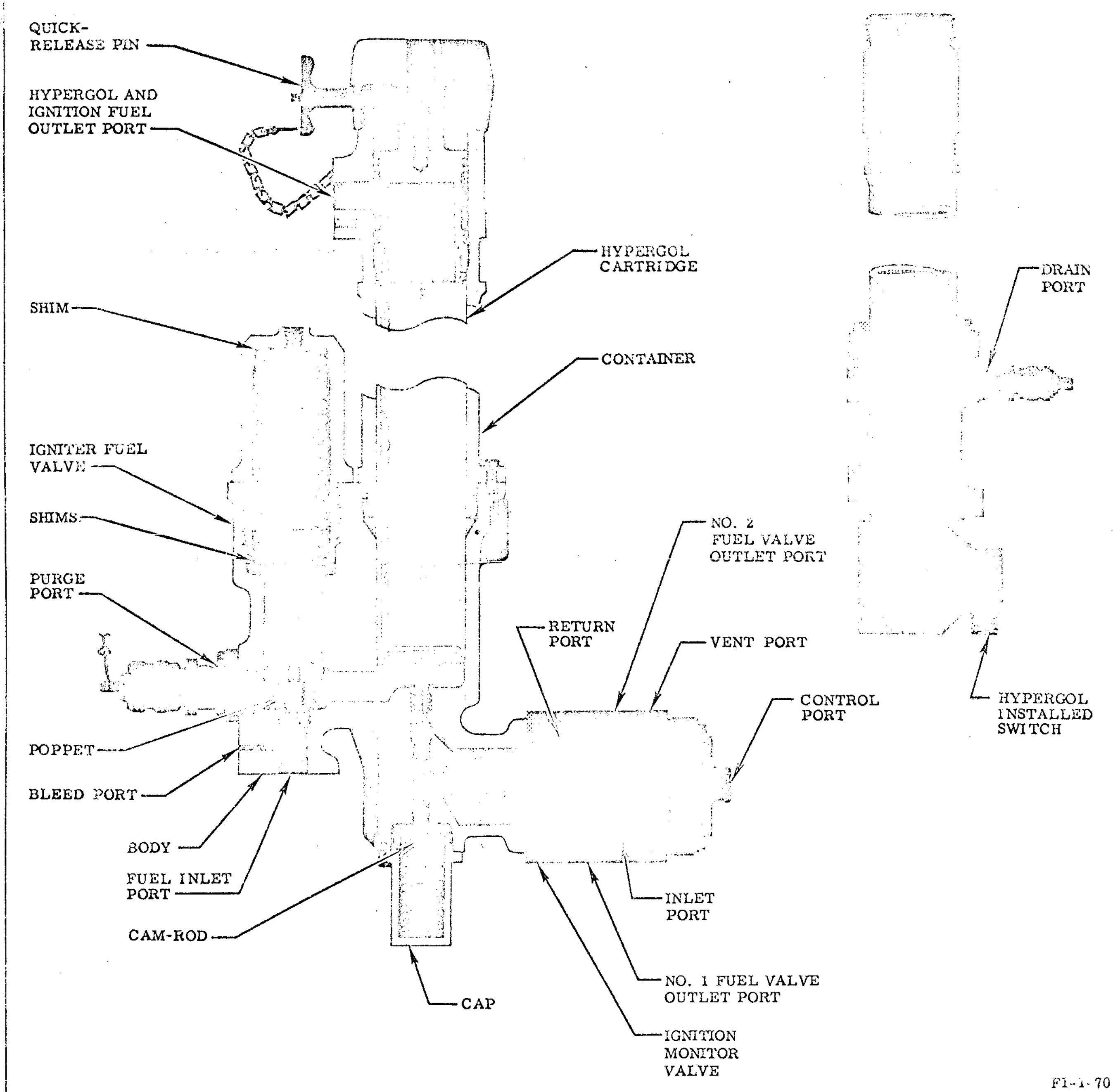


Figure 1-35. Hypergol Manifold

1-93. On engines incorporating MD96 change, transducers, harnesses, and related hardware that make up the auxiliary instrumentation system are removed, with the exception of the heat exchanger oxidizer inlet flowrate measurement transducer. The heat exchanger oxidizer flowmeter and associated electrical harness are retained to maintain heat exchanger calibration capability. The flight instrumentation system parameters, including both the primary and auxiliary systems, are listed in figure 1-38.

IGNITER FUEL VALVE		IGNITION MONITOR VALVE	
Cracking pressure	375 ±30 psig	Actuating pressure	20 ±4 psig
Shimming effect	Each shim changes the cracking pressure 4 psig.	Recirculation flow	0.22 to 0.41 gpm

Figure 1-36. Hypergol Manifold Leading Particulars

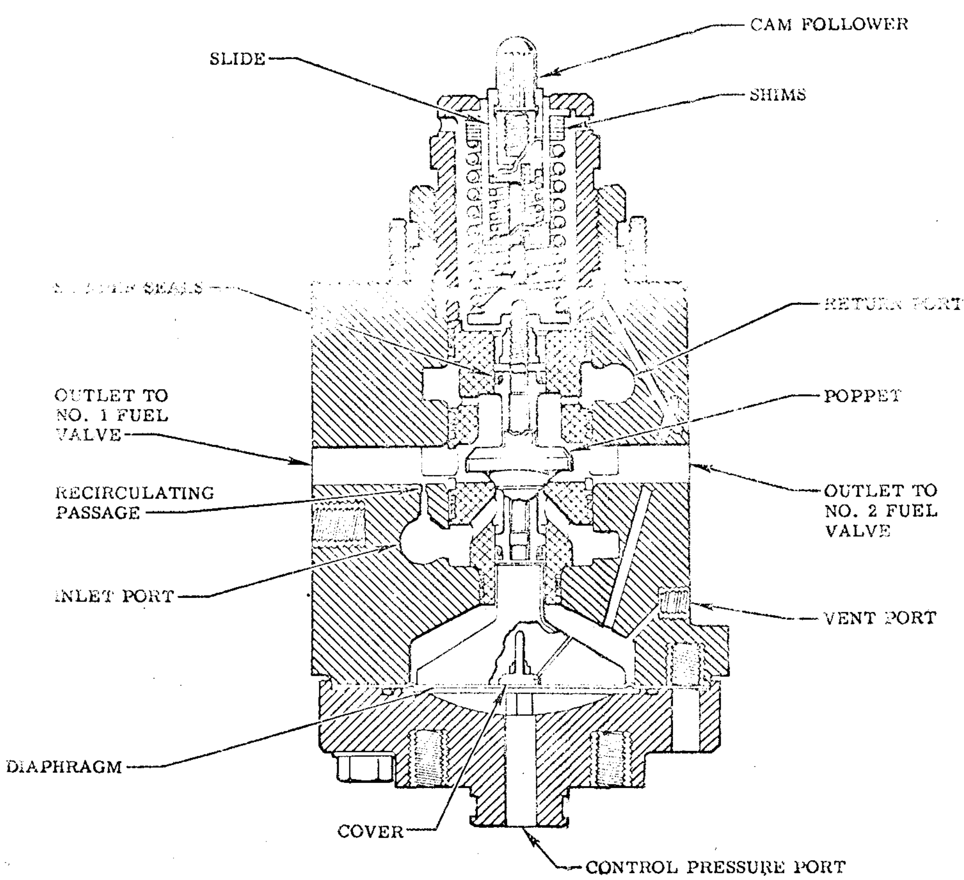


Figure 1-37. Ignition Monitor Valve

Tap No.	Parameter	Range	Accuracy (Percent)
	PRIMARY INSTRUMENTATION		
KF6a-1	Fuel pump inlet No. 1 pressure	0-200 psia	2.0
TG5c	Turbine outlet pressure	0-100 psia	2.0
PF2a-2	Fuel pump discharge No. 2 pressure	0-2,500 psia	2.0
CG1c	Combustion chamber pressure	0-1,500 psia	0.5
GG1d	Gas generator chamber pressure	0-1,500 psia	1.0
PO2a-2	Oxidizer pump discharge No. 2 pressure	0-2,000 psia	2.0
NH5c	Common hydraulic return pressure	0-500 psia	2.0
LB1a	Oxidizer pump bearing jet pressure	0-1,000 psia	2.0
LS1	Oxidizer pump bearing No. 1 temperature	0° to 400° F	2.0
TG4a(a)	Turbine inlet manifold temperature	0° to 2,000° F	2.0
CGT1	Engine environmental temperature	0° to 1,500° F	2.0
F44	Heat exchanger oxidizer inlet flow	20-100 gpm	2.0
	AUXILIARY INSTRUMENTATION(b)		
PO7a	Oxidizer pump seal cavity pressure	0-50 psia	2.0
HH2a	Heat exchanger helium inlet pressure	0-500 psia	2.0
HH3a	Heat exchanger helium outlet pressure	0-500 psia	2.0
PO2a-1	Oxidizer pump discharge No. 1 pressure	0-2,000 psia	2.0
HO1b	Heat exchanger oxidizer inlet pressure	0-2,000 psia	2.0
HO4a	Heat exchanger GOX outlet pressure	0-2,000 psia	2.0
PF2a-1	Fuel pump discharge No. 1 pressure	0-2,500 psia	2.0
NH3a	Engine control opening pressure	0-2,500 psia	2.0
NH2a	Engine control closing pressure	0-2,500 psia	2.0
HO1a	Heat exchanger oxidizer inlet temperature	-300° to -250° F	2.0
HO4b	Heat exchanger GOX outlet temperature	-300° to +600° F	2.0
F16	Heat exchanger oxidizer inlet flow(c)	0-100 gpm	2.0

(a) Engines not incorporating MD176 change
(b) Engines not incorporating MD96 change
(c) On engines incorporating MD96 change, this measurement is retained and relocated to primary system as tap number F44.

Figure 1-38. Flight Instrumentation System Parameters

1-94. PRIMARY AND AUXILIARY JUNCTION BOX DESCRIPTION.

1-95. There are two electrical junction boxes in the flight instrumentation system: the primary junction box located in the primary system and the auxiliary junction box located in the auxiliary system. On engine incorporating MD96 change, the auxiliary junction box is deleted. The junction boxes serve as junction points for signal circuitry of respective transducers either to and from the telemetry and instrumentation system during vehicle flight or to and from the control center during engine static test. The primary junction box (figure 1-39) has provisions for eight electrical connections; the auxiliary junction box (figure 1-40) has provisions for five electrical connections. Both junction boxes are hermetically sealed to prevent possible entry of contaminants and moisture.

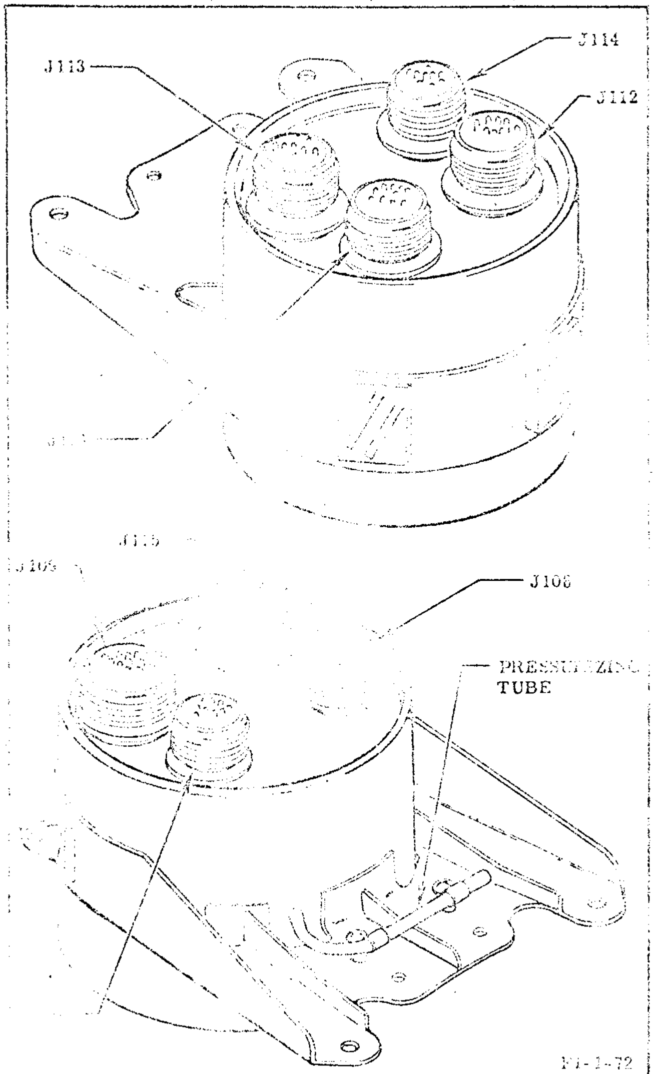


Figure 1-39. Primary Junction Box

PRESSURE TRANSDUCER DESCRIP-

[illegible] The flight instrumentation transducer [illegible] 1-41) is a [illegible] output, absolute pressure transducer [illegible] of a mechanical-force summing [illegible] to an electrical [illegible]. The [illegible] electrical bridge is [illegible] proportional to the pressure applied to the mechanical force summing network. All [illegible] of the bridge elements in the transducer [illegible] active. For [illegible] bridge element that increases impedance with increasing pressure, a [illegible] bridge element decreases impedance with increasing pressure. These elements are connected into the bridge [illegible] such a way as to obtain maximum sensitivity from the bridge. The transducer also contains the necessary circuit elements to isolate the output from the input, to provide a regulated bridge excitation voltage, to provide all necessary bridge amplification, to provide bridge output demodulation if required, and to provide all required output [illegible] be excited [illegible] a 5-vdc [illegible]. The transducer [illegible] the output [illegible] and 80 [illegible] range. [illegible] by applying [illegible] vdc [illegible] the [illegible] and 80-percent points, [illegible]. The application [illegible] this voltage [illegible] switching circuit

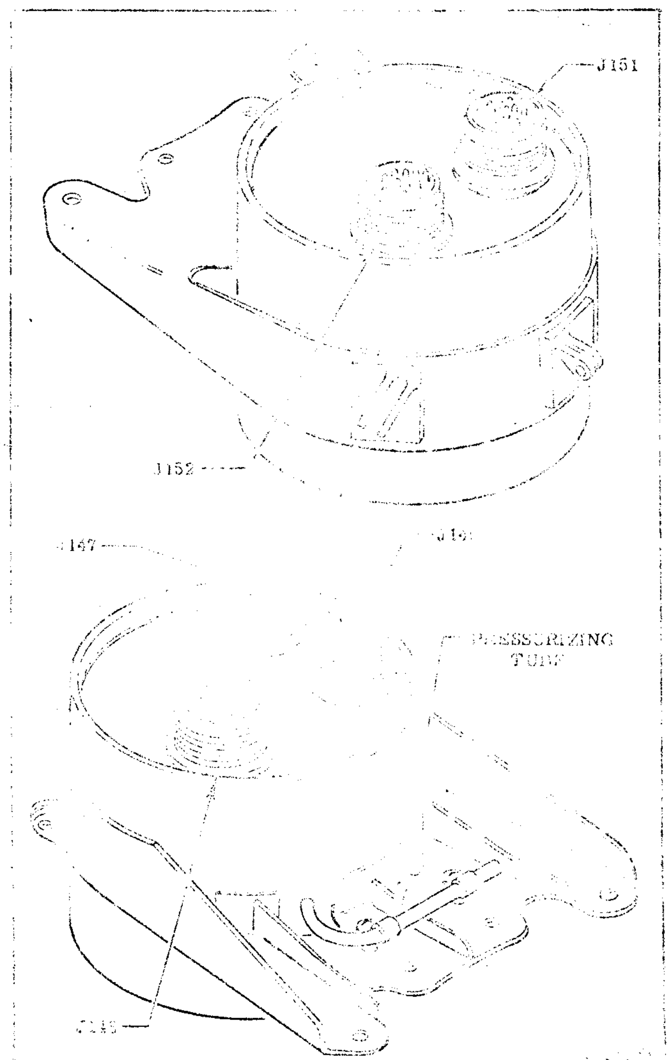


Figure 1-40. Auxiliary Junction Box

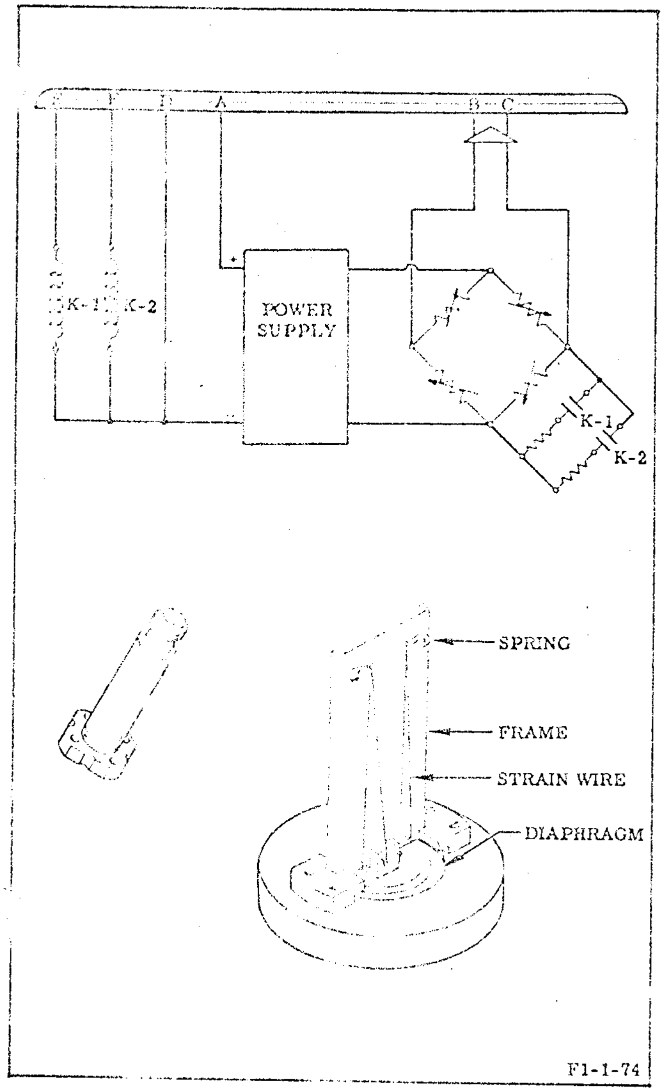


Figure 1-41. Pressure Transducer

that substitutes a resistor in the bridge network, thereby simulating the bridge output for 20 or 80 percent of the pressure range of the instrument. The transducer uses a six-pin connector with the following pin functions:

a. Pin A, positive excitation (+28 vdc)

b. Pin B, positive output (+5 vdc at full range pressure)

c. Pin C, output return

d. Pin D, excitation return

e. Pin E, 20-percent calibration (+28 vdc)

f. Pin F, 80-percent calibration (+28 vdc)

1-98. TEMPERATURE TRANSDUCER DESCRIPTION.

1-99. The flight instrumentation temperature transducers (figure 1-42) are of the platinum resistance type. All of the resistance bulbs have a three-wire termination that allows a bridge completion with a transmission line in opposite legs of the bridge, thereby making zero and sensitivity changes negligible with respect to variations in line length and resistance. Each transducer is supplied with its own resistance-versus-temperature calibration over a specified range. While all of the transducers operate on the same principle and the electrical connections are identical, the physical configurations of the various transducers differ with the installation and measurement requirements. Engines incorporating MD159 change have an improved common temperature transducer with glass-insulated and resistance-welded lead wires enclosed in a platinum tube and a sensing element protected by a shield.

1-100. OXIDIZER FLOWMETER DESCRIPTION.

1-101. The oxidizer flowmeter (figure 1-43) is a turbine-type, volumetric, liquid-flow transducer mounted between the heat exchanger check valve and the oxidizer inlet line to measure the flow of oxidizer entering the heat exchanger coil. The flowmeter consists of a rotor assembly that senses the oxidizer flow, flow straighteners that direct the flow of oxidizer across the rotor, and two pickup coils. The pickup coils are enclosed, moistureproof units with electrical receptacles. Each coil is electrostatically shielded and potted and contains an auxiliary isolated coil for checkout purposes. The flow of oxidizer through the flowmeter sets the rotor in motion. The angular speed of the rotor is a function of the volumetric flowrate of the oxidizer and is detected by the magnetic pickup that the flux

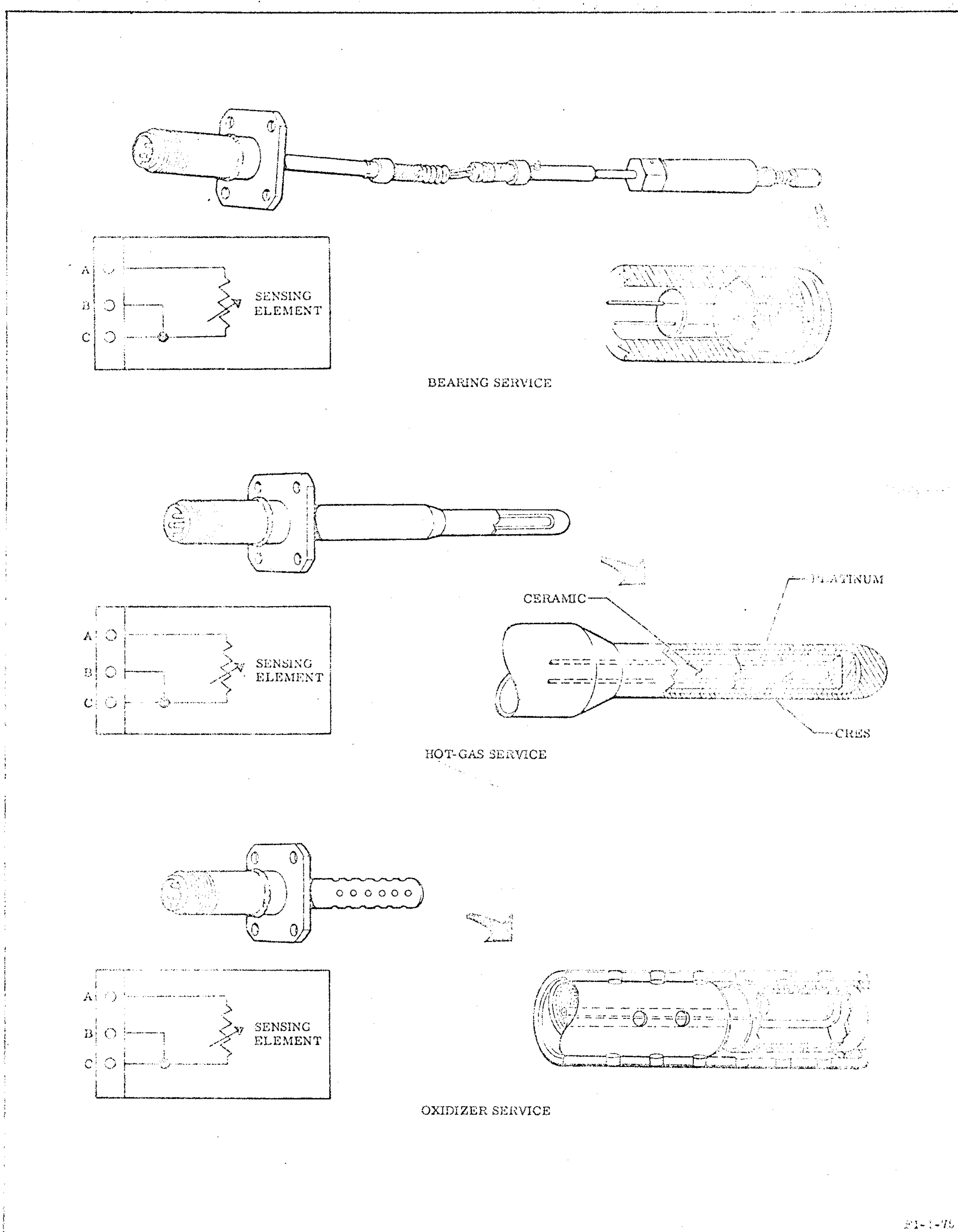


Figure 1-42. Temperature Transducers

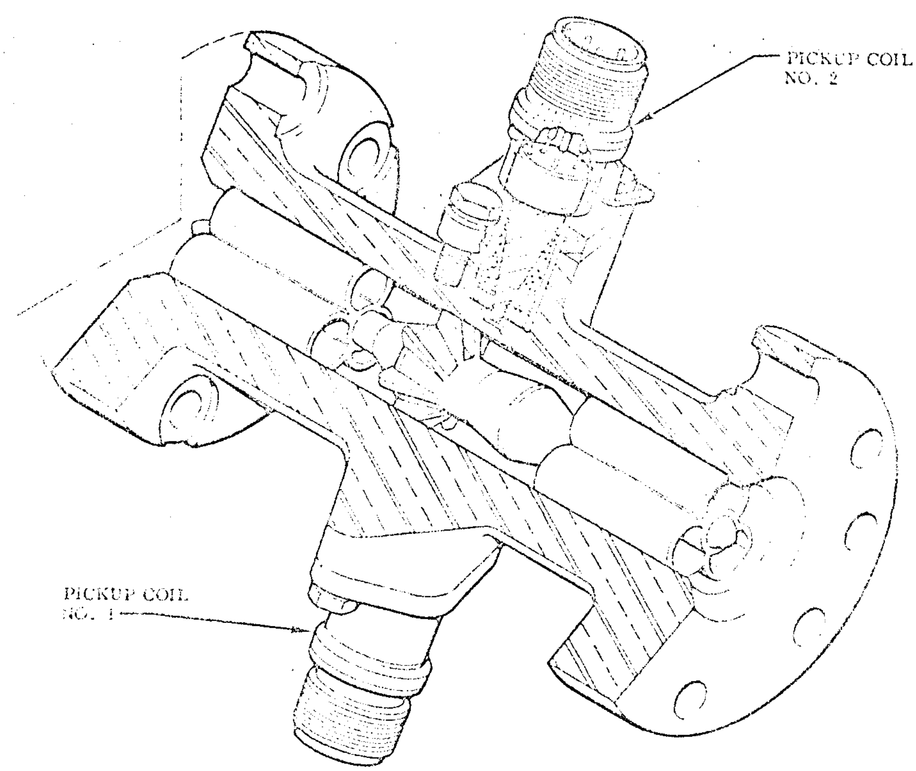


Figure 1-43. Oxidizer Flowmeter

density through the coil changes. The flux lines through the coil build up and collapse, generating an emf that can be measured at the connector. The magnitude of this emf is a function of the angular speed of the rotor, distance of the pickup from the top of the blades, and the blade material (a constant). The generated frequency is dependent on rotor speed and number of blades and is in direct correlation to flowrate. For checkout purposes, a sinusoidal input at 200 cps with a 10-volt peak on the auxiliary coil will produce a 1-3 volt peak signal at the same frequency on the primary or output coil.

1-102. SPEED TRANSDUCER DESCRIPTION.

1-103. The flight instrumentation system utilizes one speed transducer (figure 1-44). The transducer is a magnetic pickup type used to sense turbopump speed. The assembly consists of a probe section that houses the pickup coils, an adapter section (welded between the probe and electrical receptacle) that is threaded to allow installation of the unit into the torque gear housing of the turbopump, an electrical receptacle, and a pickup coil that serves as a

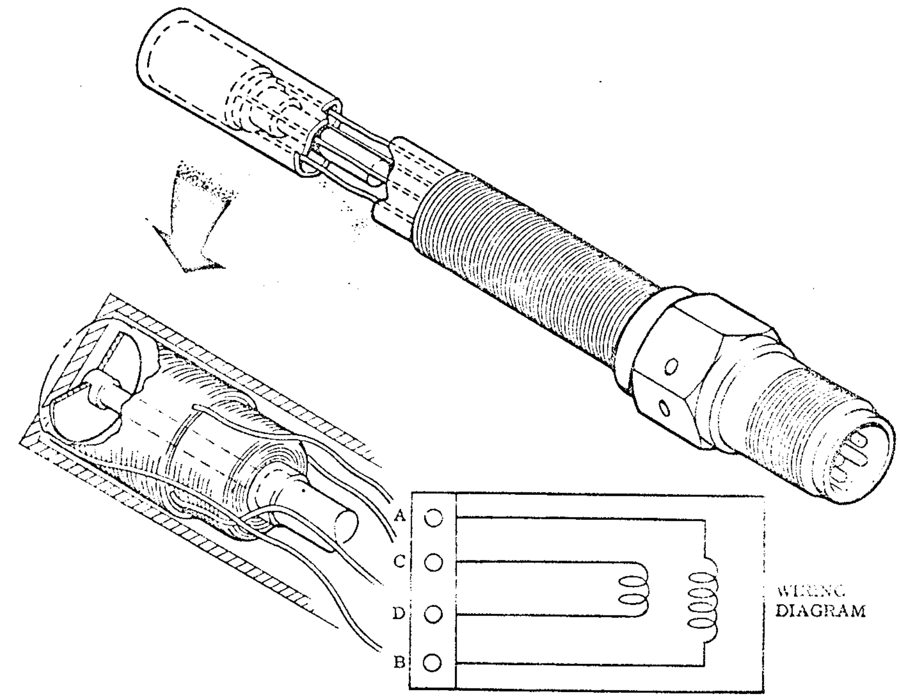


Figure 1-44. Speed Transducer

pulse generator. With the transducer installed, the tip of the probe aligns with the two-hole tachometer on the turbopump torque gear sleeve. As the turbopump shaft rotates and each hole passes the tip of the probe, the flux density of the pickup coil is interrupted. The buildup and collapse of the flux lines generate a voltage across the leads. This voltage, proportional to the pump shaft speed, is then conditioned for recording. The magnitude of the voltage is dependent on the angular speed of the turbopump shaft, the distance between the pickup coil and torque gear sleeve, and the medium of the gap. The frequency is determined by the angular speed of the pump shaft, and the number of holes in the torque gear sleeve.

1-104. THERMAL INSULATION SYSTEM DESCRIPTION.

1-105. Thermal insulation (figure 1-45) is supplied to protect the engine from extreme temperature environment caused by plume radiation and back-flow during vehicle flight. Thermal insulators for the engine are of two types, foil-batt and asbestos blanket.

1-106. Foil-batt insulators are preformed segments constructed of random fiber batting secured between two layers of textured inconel foil. The thickness of the thrust chamber insulator inner foil is 0.004 inch; outer foil thickness is 0.006 inch. Cocoon insulator foils are 0.006 inch thick. The cocoon insulator inner foil is vented to prevent ballooning due to expansion of gases trapped between the layers of foil. These insulators are used to cover large, flat areas of the thrust chamber and nozzle extension, heat exchanger lines and bellows, customer connect (wrap-around) lines, and the cocoon area (thrust chamber throat to interface panel).

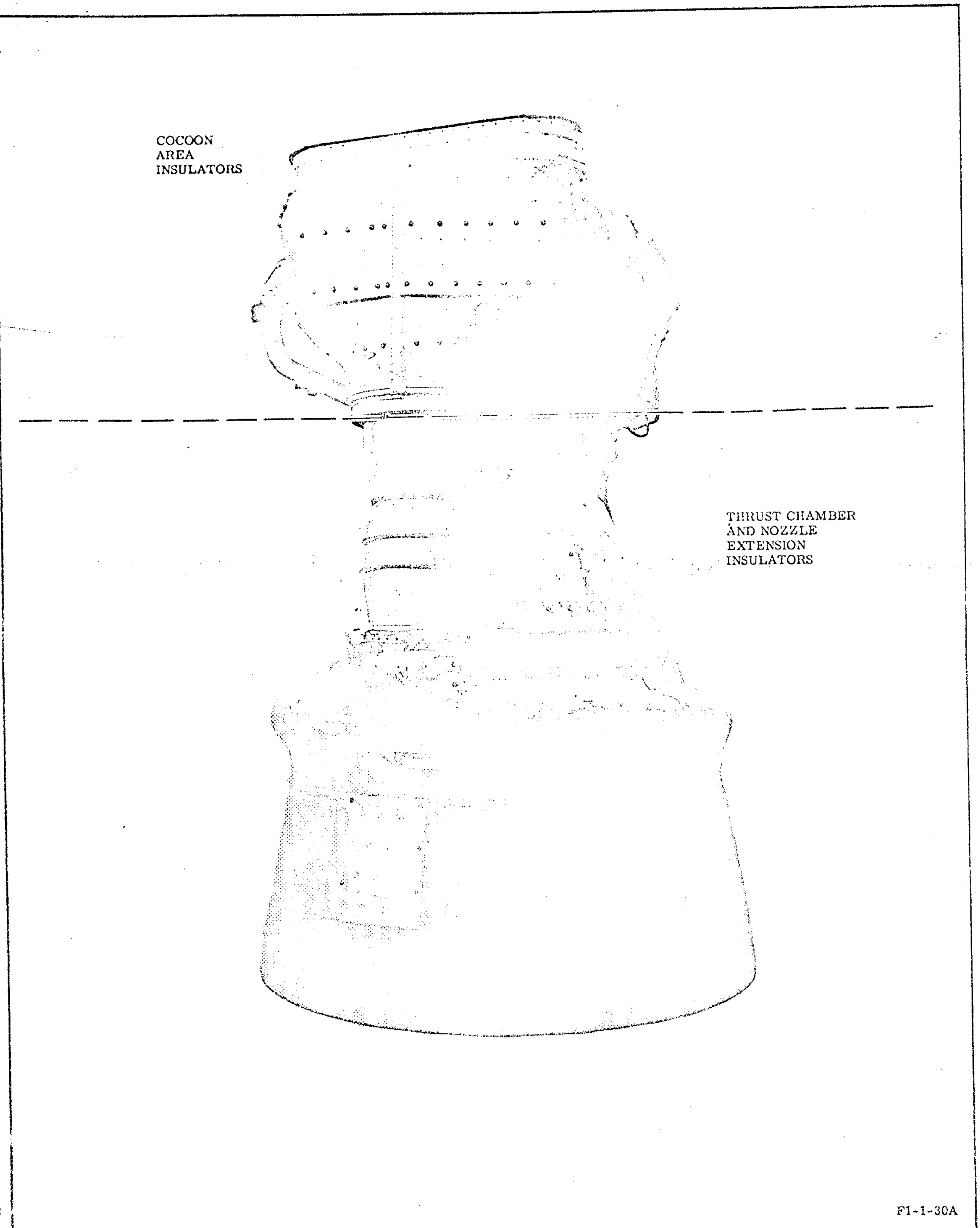


Figure 1-45. Engine Thermal Insulation

1-107. Asbestos blanket insulators are composed of multiple layers of asbestos cloth reinforced with Inconel lockwire and coated on one side with aluminum. The asbestos blankets are laminates of two, four, or five layers, depending on the location on the engine. Asbestos blankets are used on the exit end of the nozzle extension, above the oxidizer dome between the gimbal bearing and interface panel, and below the cocoon between the thrust chamber and turbine manifold.

1-108. Hardware used to secure the thermal insulation to the engine consists of support structure, screws, self-locking nuts, flat washers, nut clips, bolts, and Inconel lockwire. Support structure (brackets, straps, and supports) is located primarily in the cocoon area. Protruding studs are percussion-welded onto hatbands of the thrust chamber to support and secure insulator panels. Brackets with nutplates are provided to secure insulator panels to the nozzle extension.

1-109. ENGINE PURGE AND DRAIN SYSTEM DESCRIPTION.

1-110. The engine purge and drain system (figure 1-46) provides a means of inhibiting contamination in the critical areas of the engine and permits safe disposition of expended coolant fluids, residual propellants, and seal leakage fluids. The engine purge system and the drain system are each divided into a service mode system and an operational mode system.

1-111. SERVICE MODE PURGE SYSTEM DESCRIPTION.

1-112. The service mode purge system utilizes facility-supplied gaseous nitrogen to expel residual propellants and fluids from the engine. The service mode purge system consists of quick-disconnect fittings on the No. 1 and No. 2 fuel valves for supplying gaseous nitrogen to the fuel valves and thrust chamber, one quick-disconnect on the hypergol manifold assembly to purge the hypergol container and ignition fuel hose of residual fluids, a quick-disconnect on the ignition monitor valve sense tube to purge the tube of residual fluid, a quick-disconnect at the bearing coolant control valve to purge the bearing coolant delivery lines of residual coolant fluid and preservative compound, and six threaded bosses on the oxidizer dome to purge the oxidizer dome and injector of residual flushing fluid.

1-113. OPERATIONAL MODE PURGE SYSTEM DESCRIPTION.

1-114. The operational mode purge system utilizes vehicle- and facility-supplied gaseous nitrogen to establish a pressure barrier to protect the oxidizer sections of the engine from contamination. The gaseous nitrogen is supplied to the engine through two purge fittings. One of the purge fittings provides gaseous nitrogen from the vehicle at 80 psig for purging the oxidizer pump intermediate seal. The other purge fitting directs gaseous nitrogen at 800 psig to the gas generator and No. 1 and No. 2 oxidizer valves to prevent contaminants from entering the oxidizer sections of the gas generator and thrust chamber during ignition and transition into mainstage.

1-115. SERVICE MODE DRAIN SYSTEM DESCRIPTION.

1-116. The service mode drain system enables residual fuel and control system fluid to be drained from the engine during maintenance and post-test securing of the engine. The service mode drain system consists of quick-disconnect fittings and drain plugs located at low points of the propellant feed and control systems. The quick-disconnect fittings utilized for draining residual fuel are located on the No. 1 and No. 2 fuel inlet elbows, No. 1 and No. 2 high-pressure fuel ducts, thrust chamber fuel inlet manifold, hypergol manifold, and gas generator. Quick-disconnect fittings for draining the control system fluid are located on the control system engine return line, control system engine supply line, and gimbal actuator return line. Four drain plugs located on the thrust chamber fuel return manifold permit the thrust chamber tubes to be drained of residual fuel, prefill fluid, or flushing solvent.

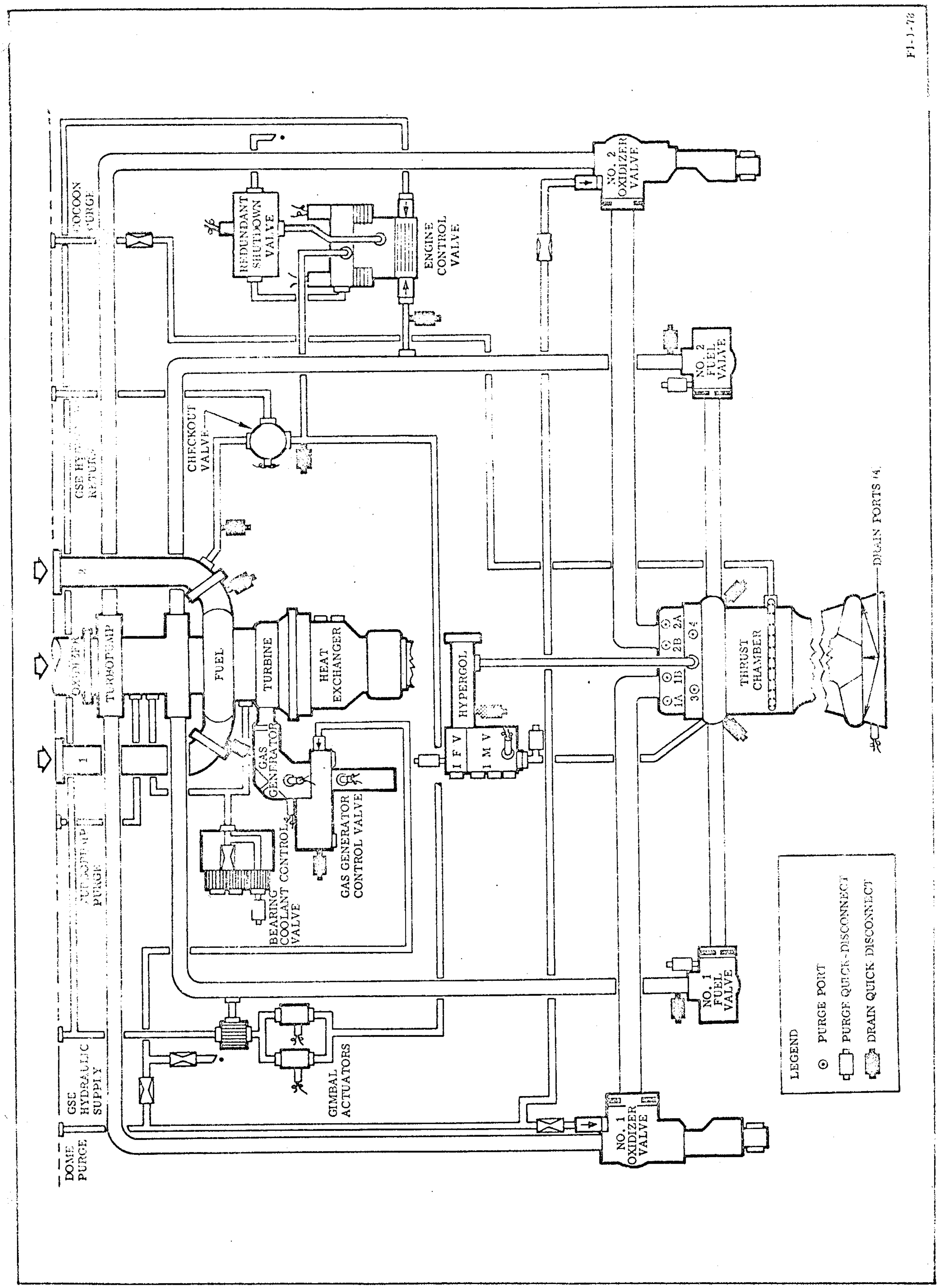


Figure 1-46. Engine Purge and Drain Schematic

1-117. OPERATIONAL MODE DRAIN SYSTEM DESCRIPTION.

1-118. The operational mode drain system furnishes a means of overboard disposition of fluid leakage past internal seals of certain components, and of expended bearing coolant fluid from the turbopump. The operational mode drain system consists of separate oxidizer and fuel overboard drain lines and a fuel drain manifold. Fuel and control fluid seal leakage and expended coolant fluid are collected into a single fuel overboard drain line on the No. 2 side of the engine. (See figures 1-47 and 1-47A.) The fuel drain manifold (figure 1-48) is the collective drain point for the expended coolant fluid and excess preservative compound remaining during turbopump preservative procedures. Oxidizer leakage past the primary oxidizer seal of the turbopump and the internal oxidizer seals of the No. 1 and No. 2 oxidizer valves and gas generator control valve are directed to an oxidizer overboard drain line on the No. 1 side of the engine. (See figure 1-49.) This line also directs overboard the purge flow through the oxidizer side of the turbopump intermediate seal. Paralleling the oxidizer overboard drain line on the No. 1 side of the engine is the nitrogen purge overboard drain line, which directs overboard the purge flow through the fuel side of the intermediate seal.

1-119. ENGINE OPERATIONAL REQUIREMENTS.

1-120. The engine requires a source of pneumatic pressure, electrical power, and propellants for engine operation. A ground-supplied hydraulic pressure source, hypergolic fluid, prefill fluid, and pyrotechnic igniters are required for engine start. Figure 1-50 lists facility-supplied inputs required for engine operation.

1-121. ENGINE OPERATION.

1-122. Engine operation is described within this section in terms of engine preparation stage, engine start and ignition, engine mainstage, and engine cutoff for a typical single engine in a test facility. This description is supplemented by an engine start and an engine cutoff block diagram flow chart (figures 1-51 and 1-52), an engine system schematic reflecting engine conditions during the respective stages of operation (figures 1-53, 1-54, 1-55, and 1-56), and engine start and cutoff sequence flow charts (figures 1-57 and 1-58). The sequence of engine start and shutdown is controlled by an electrical-hydraulic-mechanical system. Electrically, relays in the facility equipment, and solenoids and switches on the engine, are employed to start, maintain, and stop the sequence. An orificed hydraulic control system powers and sequences the propellant and control valves. Also, mechanically linked devices assist in sequencing propellant valve actuation.

1-123. ENGINE PREPARATION STAGE.

1-124. The engine preparation stage is that activity during which it is determined that the engine and the test facility are in a satisfactory condition for a safe engine start. The culmination of this activity is an ENGINE PREPARATION COMPLETE signal which, in conjunction with a facility preparation complete signal, makes electrical power available to the engine start switch.

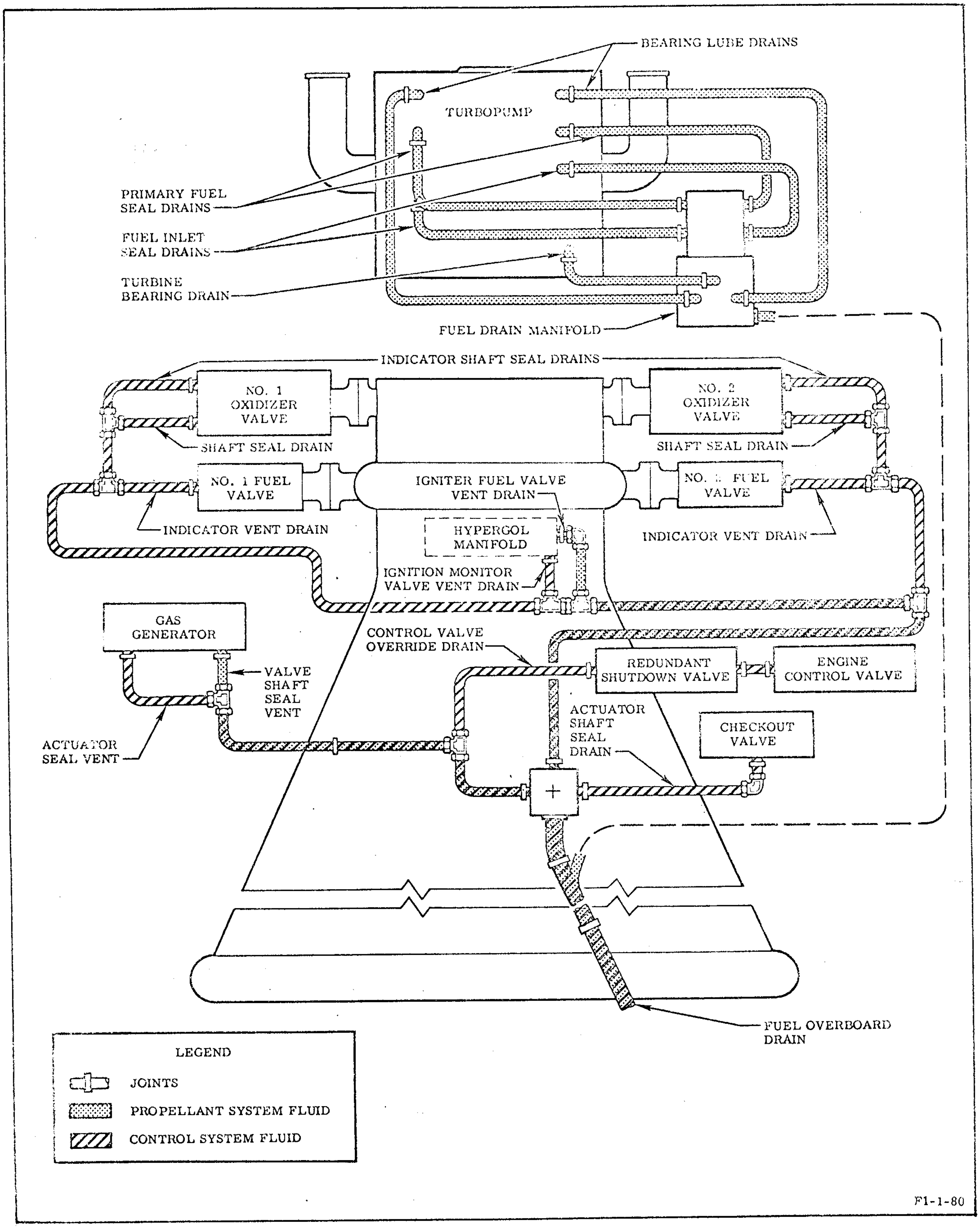


Figure 1-47. Engine Fue' and Control Fluid Overboard Drain Schematic (Engines No. Incorporating MD145 Change)

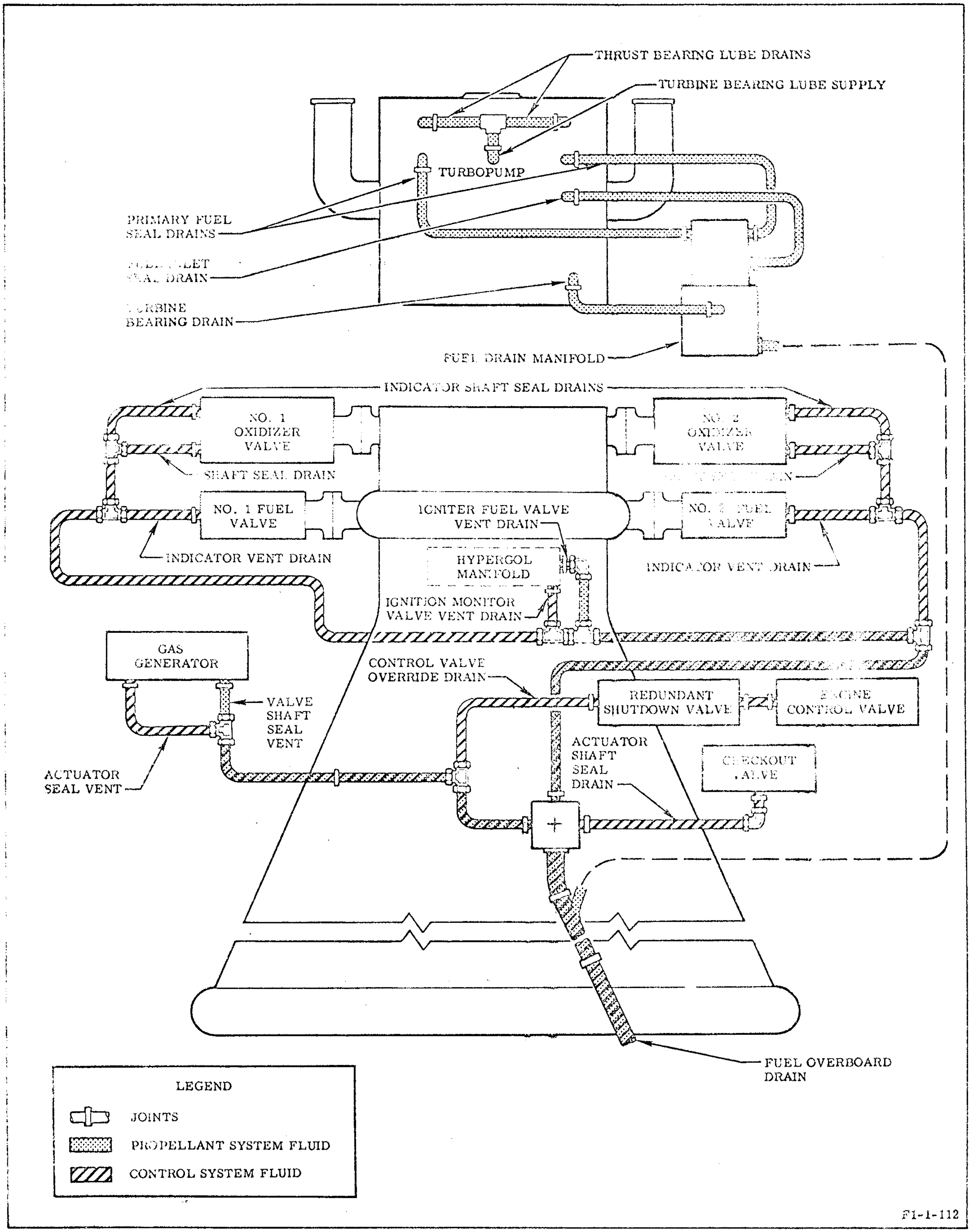


Figure 1-47A. Engine Fuel and Control Fluid Overboard Drain Schematic (Engines Incorporating MD145 Change)

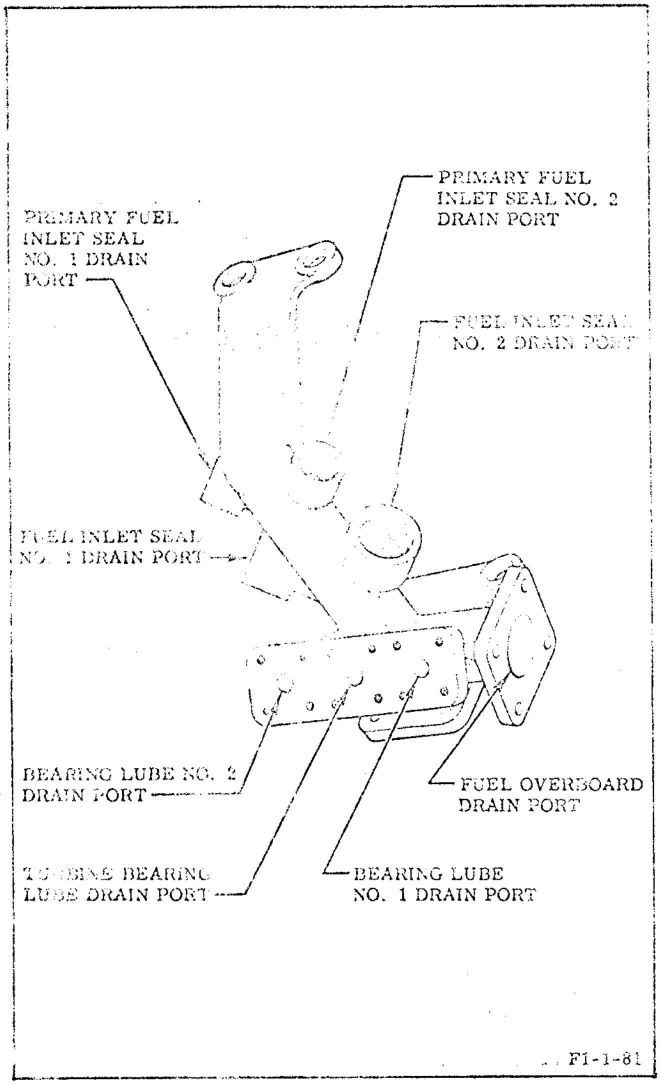


Figure 1-48. Fuel Drain Manifold

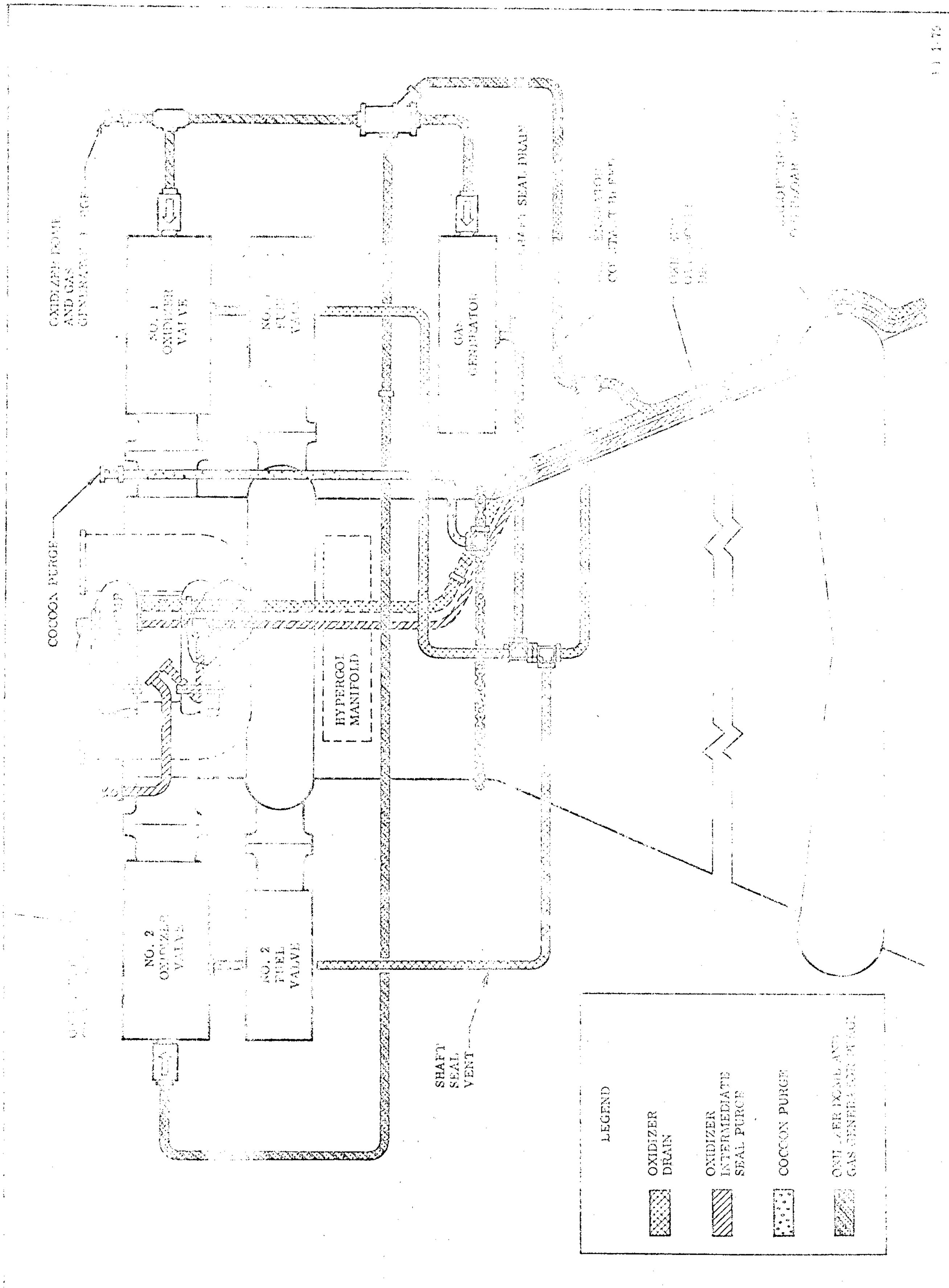


Figure 1-49. Engine Purge and Oxidizer Overboard Drain Schematic

PROPELLANTS	
Liquid oxygen (MIL-P-25508)	Gas generator and thrust chamber combustion
Propellant kerosene (MIL-P-25576)	Gas generator and thrust chamber combustion
PNEUMATICS	
800 psig gaseous nitrogen (MIL-P-27401)	Gas generator and thrust chamber domes purge
80 psig gaseous nitrogen (MIL-P-27401)	Turbopump oxidizer seal purge
100-200 psig gaseous nitrogen (MIL-P-27401)	Thermal insulation cocoon purge
250 psia helium (Bureau of Mines, Grade A)	Heat exchanger (vehicle fuel tank pressurization)
ELECTRICAL POWER	
5 vdc	Engine instrumentation system (valve potentiometer)
28 vdc	Engine control system
28 vdc	Engine instrumentation system (transducers)
5 vdc	Engine instrumentation system (transducer checkout)
220 vac	Turbopump heaters
500 vac	Engine pyrotechnic igniters
MISCELLANEOUS	
Pyrotechnic igniters (2)	Gas generator ignition
Pyrotechnic igniters (2)	Thrust chamber nozzle extension ignition
Hypergol igniter (1)	Thrust chamber ignition
Prefill fluid (105 gallons of ethylene glycol and water)	Thrust chamber tube inert prefill
1,500 psig propellant kerosene (MIL-P-25576) or RJ-1 fuel (MIL-F-25558) pressure	Fluid power supply (prior to mainstage)

Figure 1-50. Engine Facility Requirements

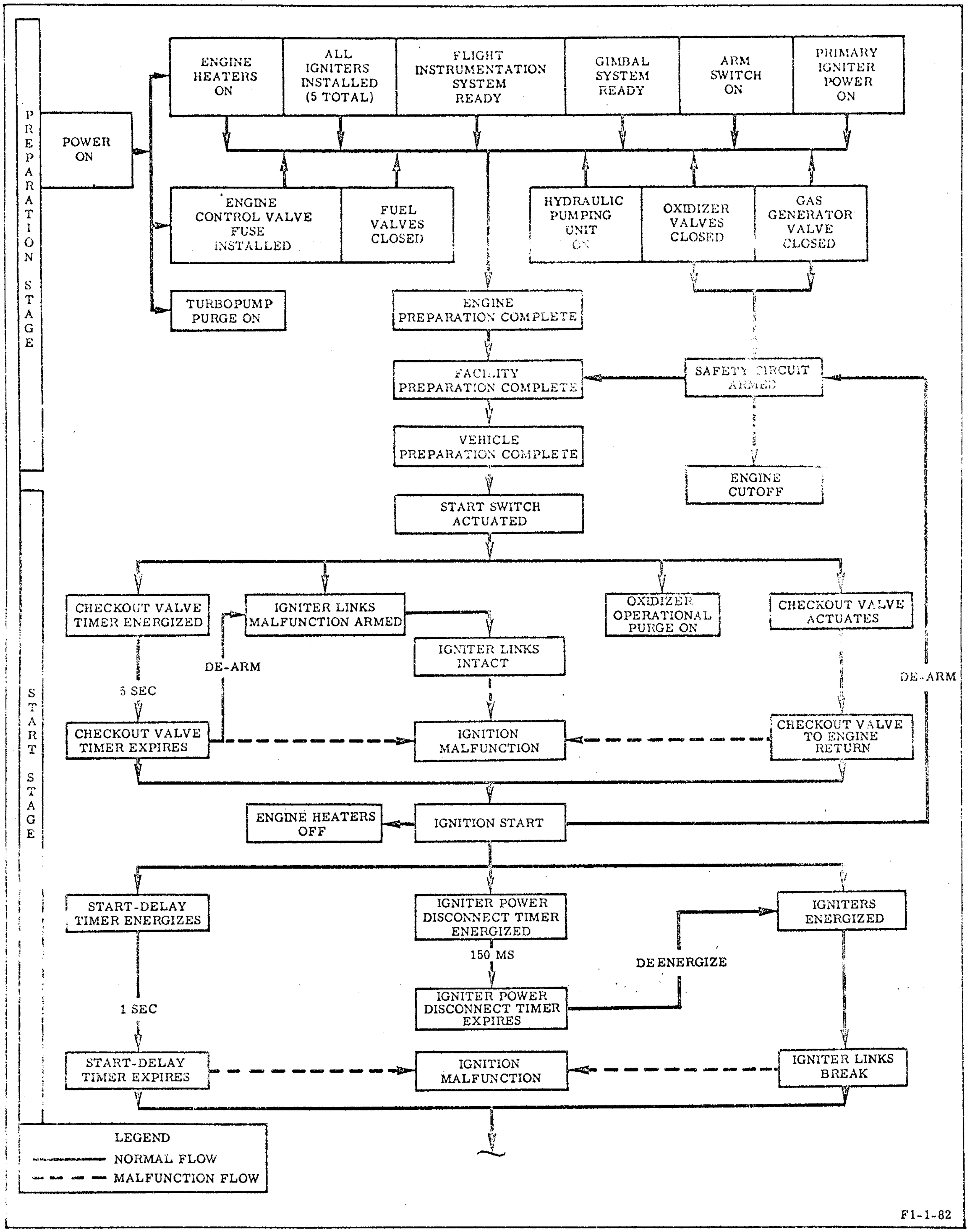


Figure 1-51. Engine Start Sequence (Typical Single Engine) (Sheet 1 of 2)

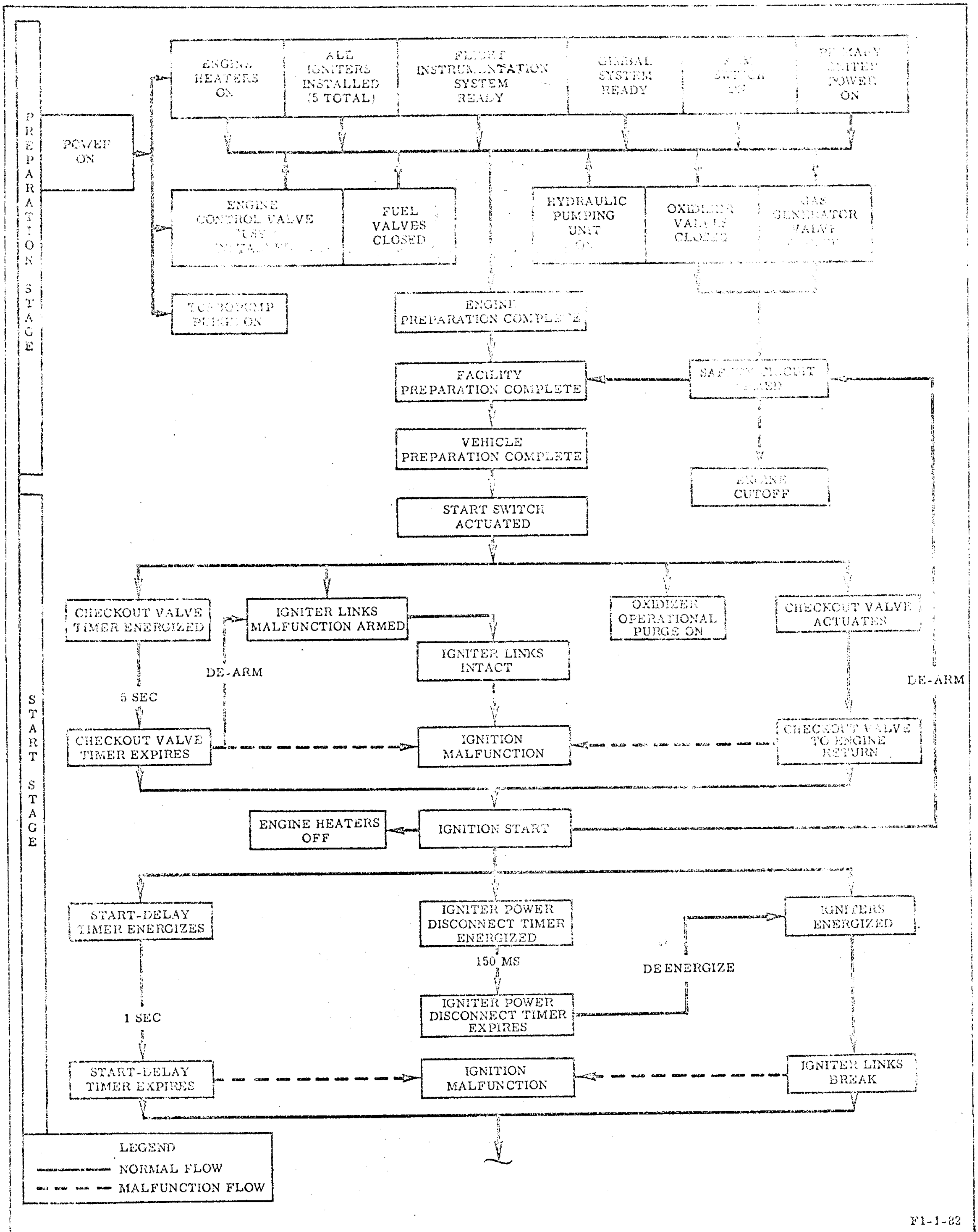


Figure 1-51. Engine Start Sequence (Typical Single Engine) (Sheet 1 of 2)

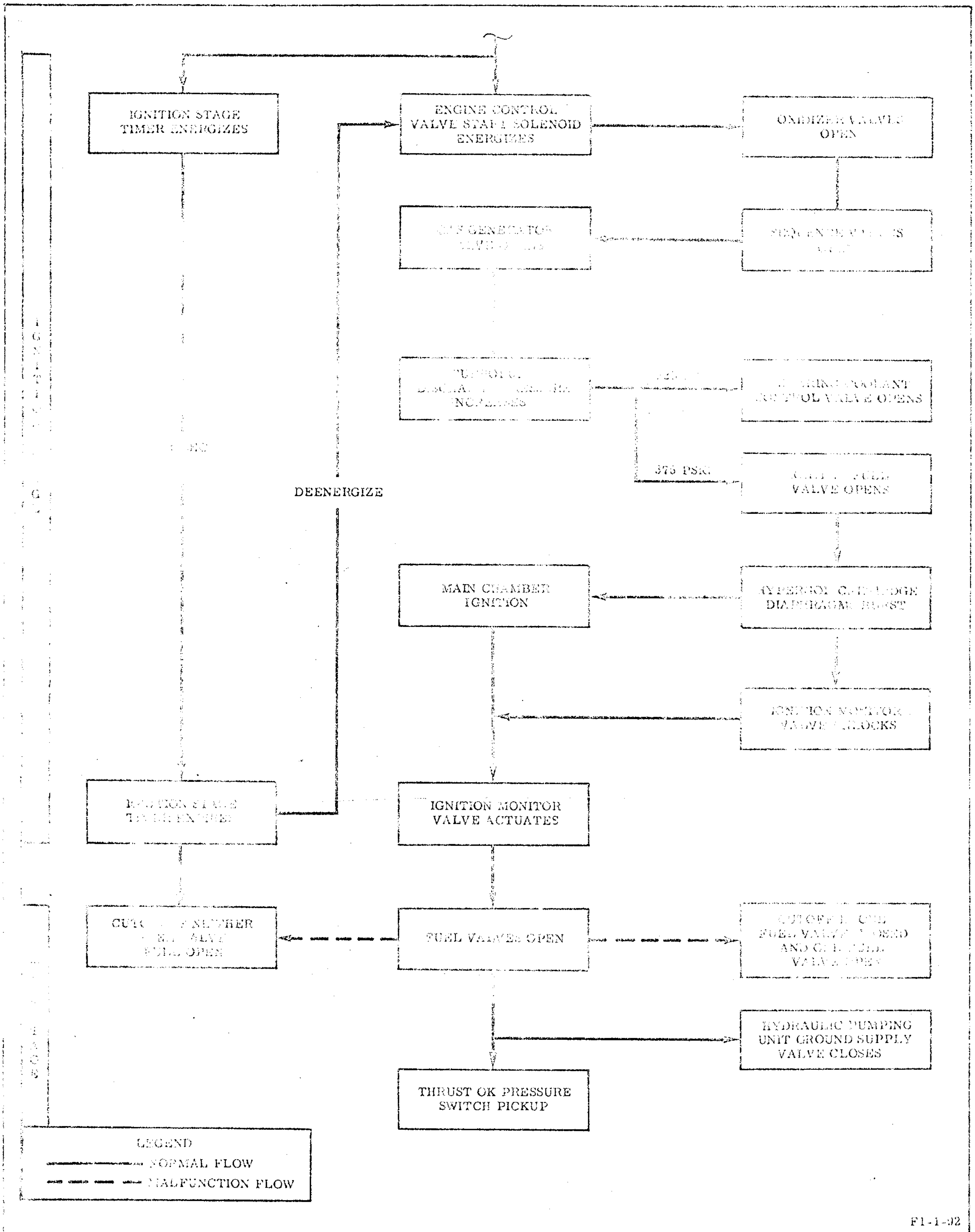


Figure 1-51. Engine Start Sequence (Typical Single Engine) (Sheet 2 of 2)

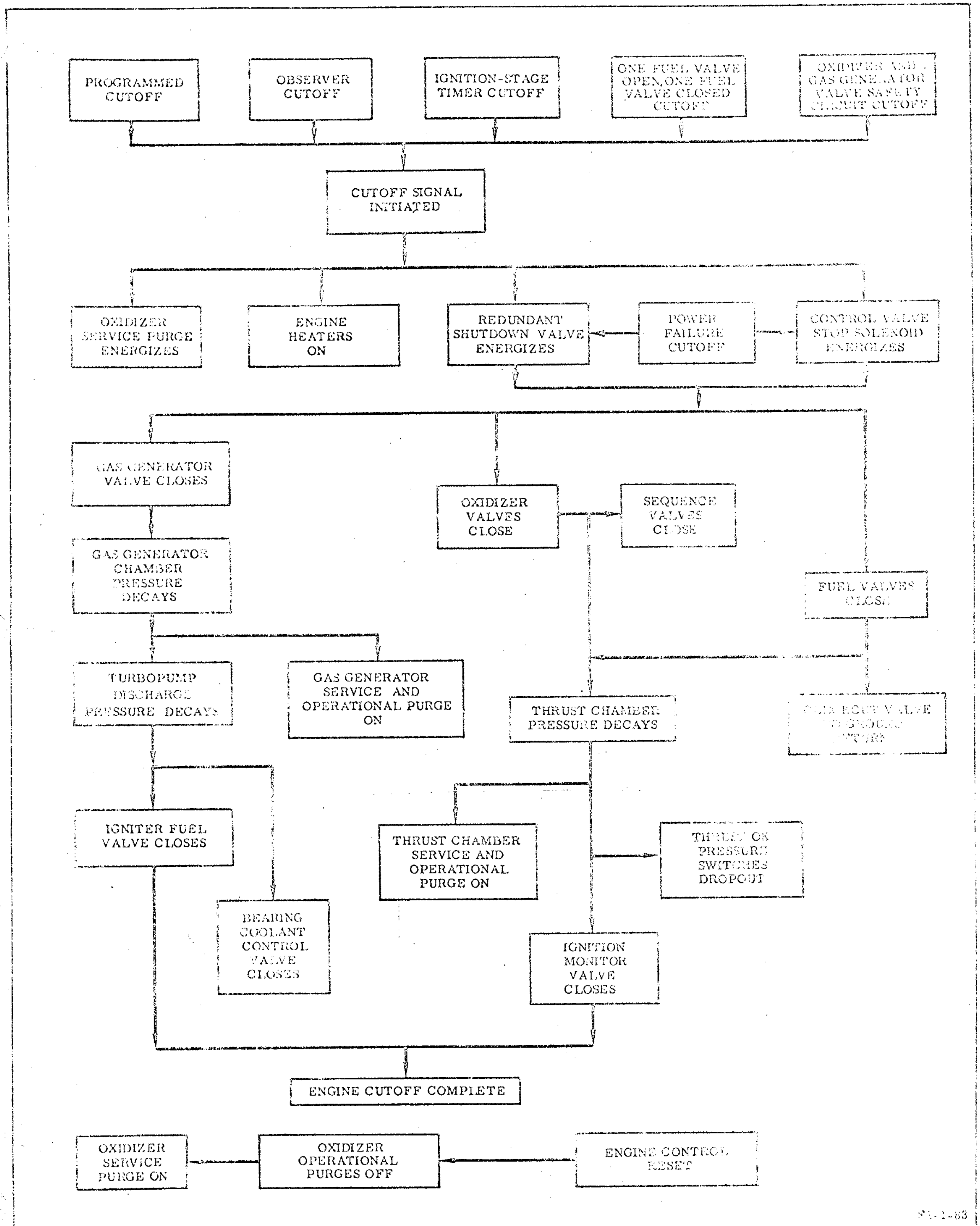


Figure 1-52. Engine Cutoff Sequence (Typical Single Engine)

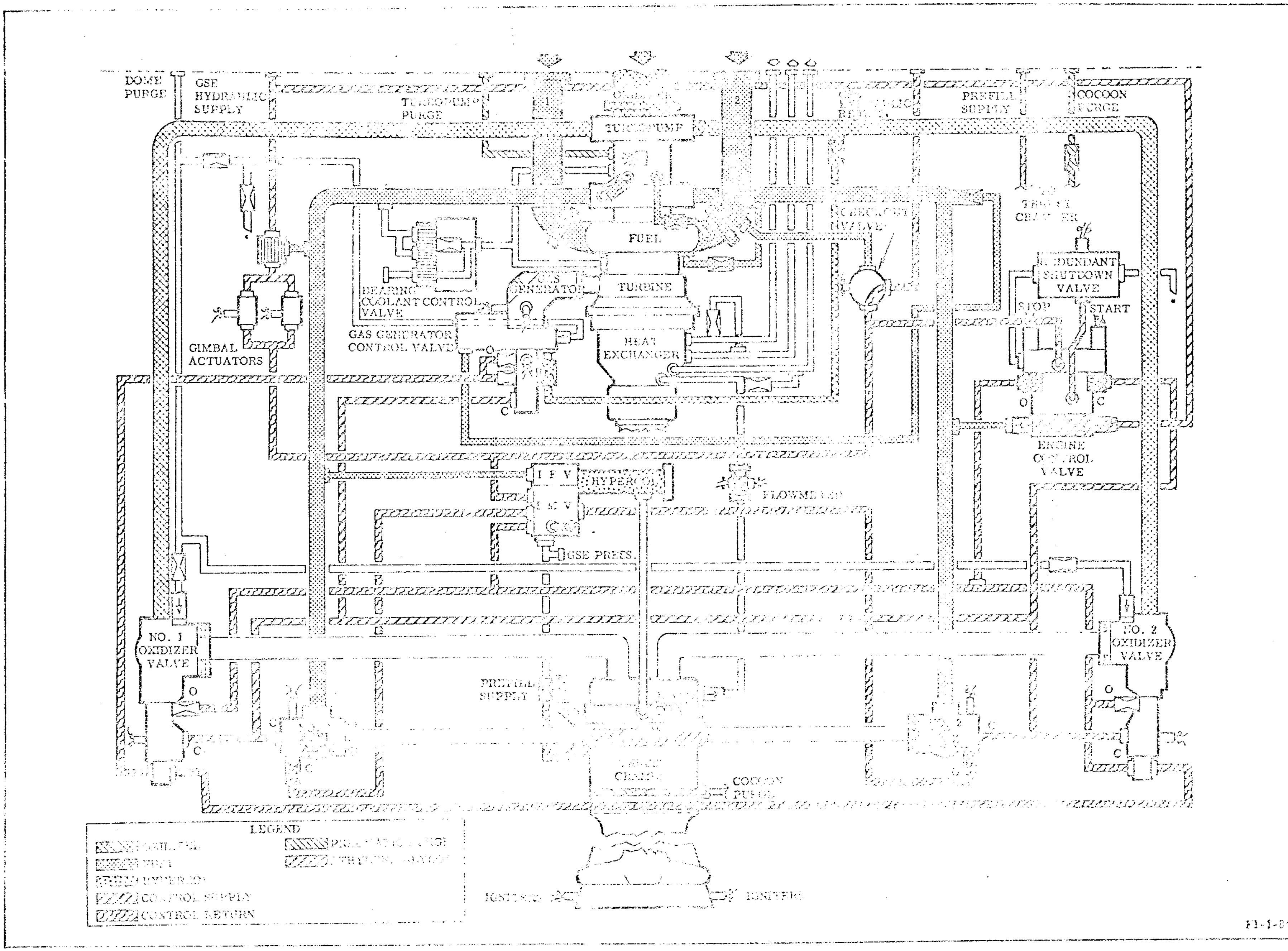


Figure 1-53. Engine Preparation Complete (Typical Single Engine)

1-125. ENGINE START AND IGNITION STAGE.

1-126. The engine start and ignition stage is that part of the engine operation that is initiated with the manual actuation of the engine start switch and extends through the period during which the propellant valves are opened, combustion of the propellants is established, and transition into mainstage takes place. The actuation of the engine start switch electrically initiates the automatic start sequence that causes the checkout valve to rotate to the engine return position, the oxidizer dome operational purge to come on, and a checkout valve timer to energize. When the checkout valve timer expires and the checkout valve is in the engine return position, the turbopump heaters are deenergized, electrical power is applied to the gas generator and nozzle extension pyrotechnic igniters, and a start delay timer energizes. When the start delay timer expires and burning of the igniters is electrically verified by the severence of the igniter links, the start solenoid of the engine control valve and an ignition stage timer are energized. The actuation of the start solenoid causes the control spool of the engine control valve to shuttle, which removes ground-supplied hydraulic closing control fluid from the propellant valves and applies the control fluid to the opening port of the No. 1 and No. 2 oxidizer valves and the inlet port of the ignition monitor valve.

1-127. Opening of the oxidizer valves permits oxidizer to flow to the combustion zone of the thrust chamber and also mechanically opens the sequence valves. When the sequence valves open, control fluid is directed to the opening port of the gas generator control valve. Opening of the gas generator control valve admits propellants to the gas generator combustor where the propellants are ignited by the gas generator igniters. The resultant fuel-rich hot gases are directed through the turbine and the thrust chamber exhaust manifold to the nozzle extension where the gases combine with the oxidizer-rich atmosphere in the thrust chamber and are ignited by the nozzle extension igniters. Flow of the gas generator combustion gases through the turbine causes turbopump rotation and the attendant increase of fuel and oxidizer pump discharge pressure.

1-128. When the fuel pump discharge pressure attains approximately 225 psig, the bearing coolant control valve opens and directs fuel to the turbopump bearings for lubrication and bearing cooling. When the fuel pump discharge pressure increases to approximately 375 psig, the igniter fuel valve poppet is offseated, admitting fuel to the hypergol igniter. The hypergol cartridge burst diaphragms rupture, which directs the hypergolic fluid, followed by ignition fuel, to flow to the thrust chamber combustion zone and establish ignition. The rupturing of the hypergol cartridge diaphragms unlocks the ignition monitor valve, and thrust chamber combustion pressure of approximately 20 psig, sensed at the control port of the ignition monitor valve, causes the ignition monitor valve poppet to shuttle. Shuttling of the poppet directs the control fluid at the inlet port to flow to the opening ports of the No. 1 and No. 2 fuel valves.

1-129. ENGINE MAINSTAGE.

1-130. Engine mainstage is that period of engine operation that is initiated when the engine has attained 90 percent of its rated thrust. Mainstage is signalled by the actuation of the thrust OK pressure switches. During the transition into mainstage, the control system pressure source is automatically transferred to the engine at the time engine fuel discharge pressure exceeds ground-supplied pressure. When the fuel valves reach the open position, the supply valve in the ground source control system supply line is closed. The ignition stage timer, which would have initiated an engine cutoff if the fuel valves had not opened within the time limit of the timer, expires and deenergizes the engine control valve start solenoid. The control spool is unaffected, because the spool has been hydraulically locked in the valve's open position.

1-131. ENGINE CUTOFF.

1-132. Engine cutoff is initiated electrically by simultaneously energizing the engine control valve stop solenoid and the redundant shutdown valve solenoid. When the engine control valve stop solenoid is energized, the control spool is shuttled to the valve's closed position, which removes opening pressure and applies closing

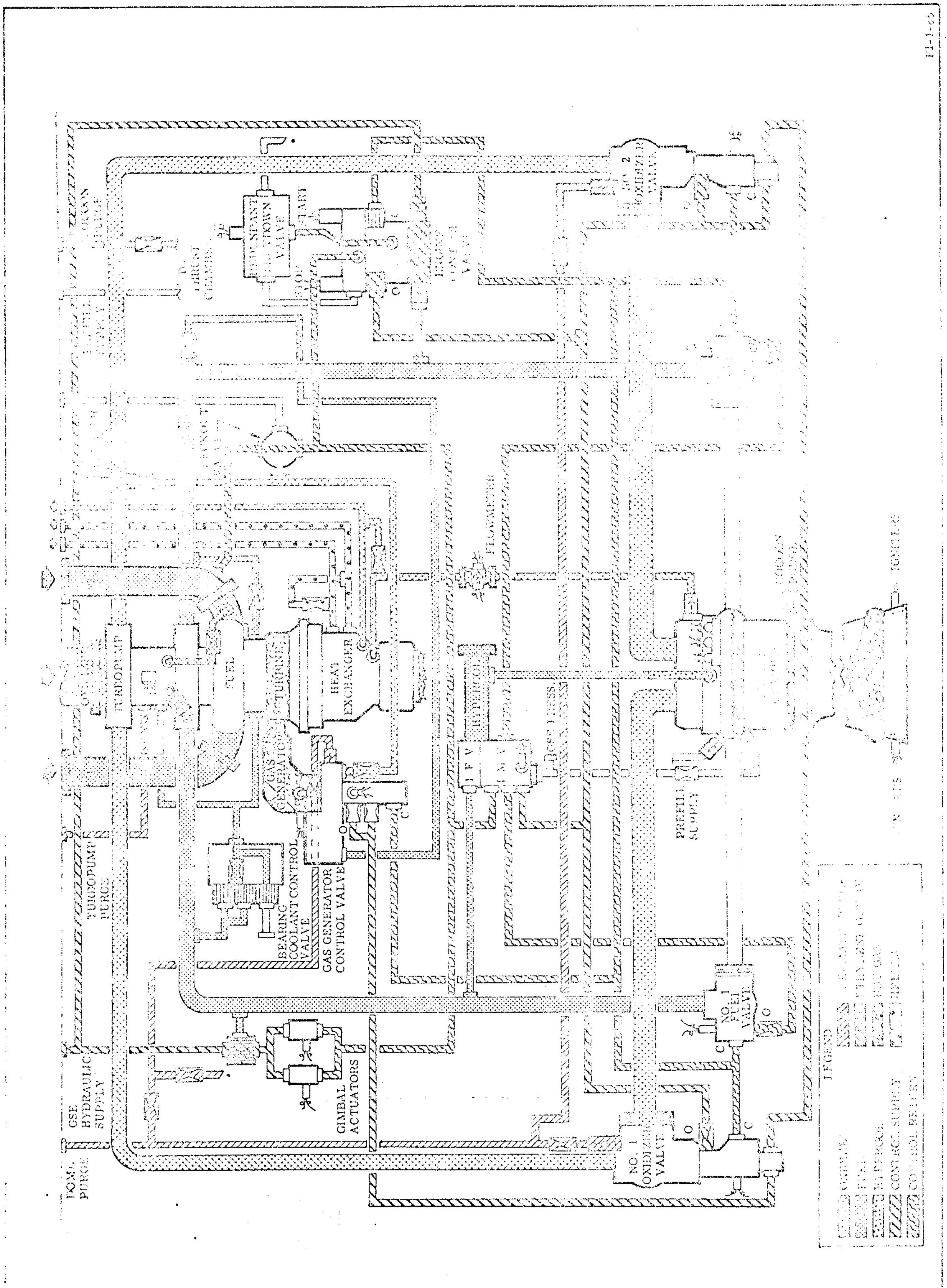


Figure 1-54. Engine Ignition Stage

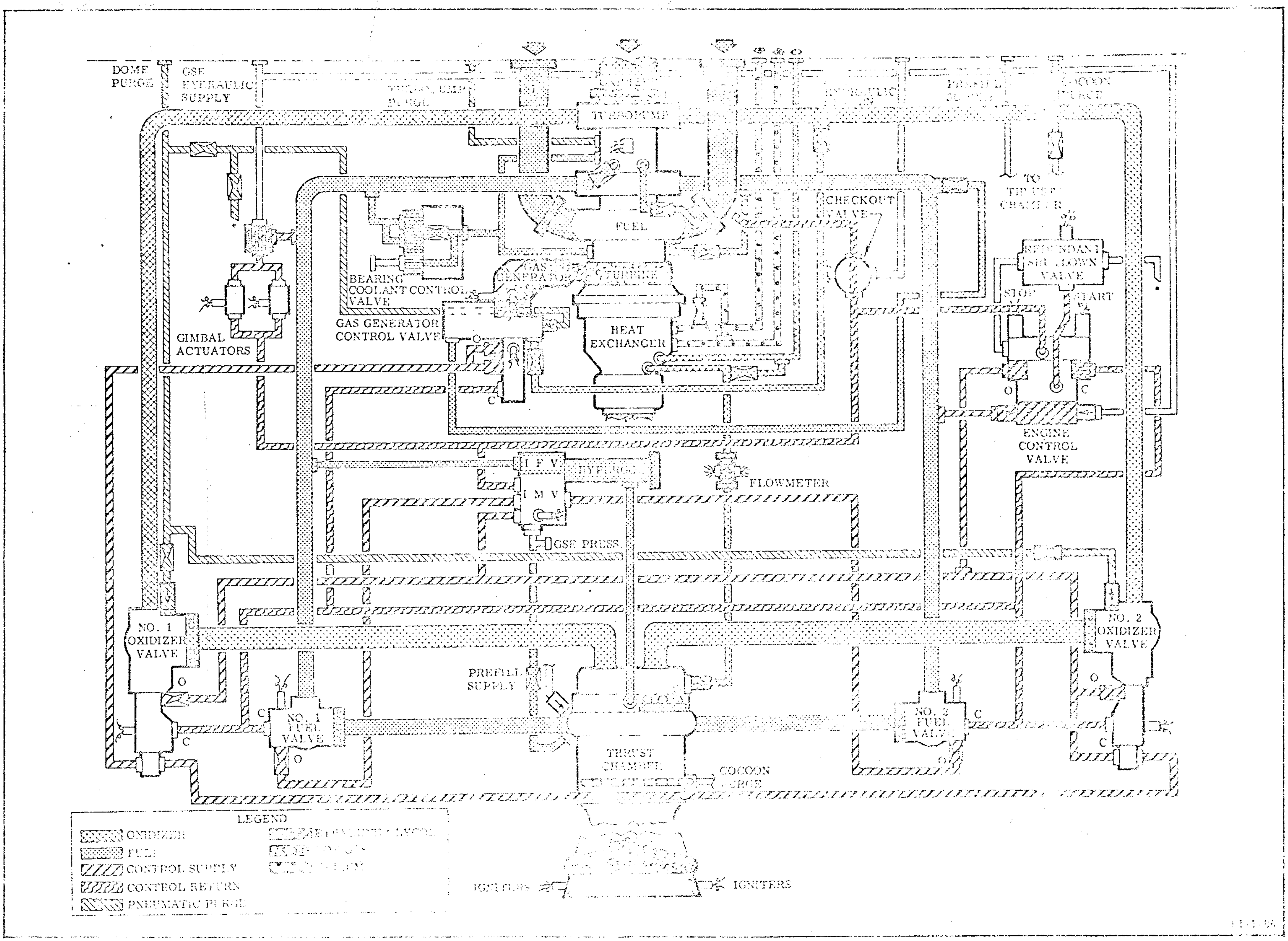


Figure 1-55. Engine Mainstage

pressure to the propellant valves. Energizing the redundant shutdown valve permits the valve to hydraulically actuate and direct control system pressure to the override port of the engine control valve. Pressure to the override port will cause the control spool to shuttle to the valve's closed position if the spool had not repositioned when the stop solenoid was energized. When closing control pressure is applied to the propellant valves, orifices in the control lines will sequence the gas generator control valve, oxidizer valves, and fuel valves closed, in that order.

1-133. At the time engine cutoff is initiated, the turbopump bearing heaters are reactivated and the oxidizer service purge is energized. Closing of the gas generator control valve removes power that drives the turbine and causes rapid decay of fuel discharge pressure. As fuel pressure decays, the igniter fuel valve and bearing coolant control valves close. Closing of the oxidizer and fuel valves causes a decay of combustion zone pressure in the thrust chamber and the resultant closing of the ignition monitor valve. When both the No. 1 and No. 2 fuel valves reach the closed position, the checkout valve is automatically returned to the ground return position and the ground source control system supply valve is reopened to supply closing pressure to the propellant valves until all residual propellants are drained from the engine.

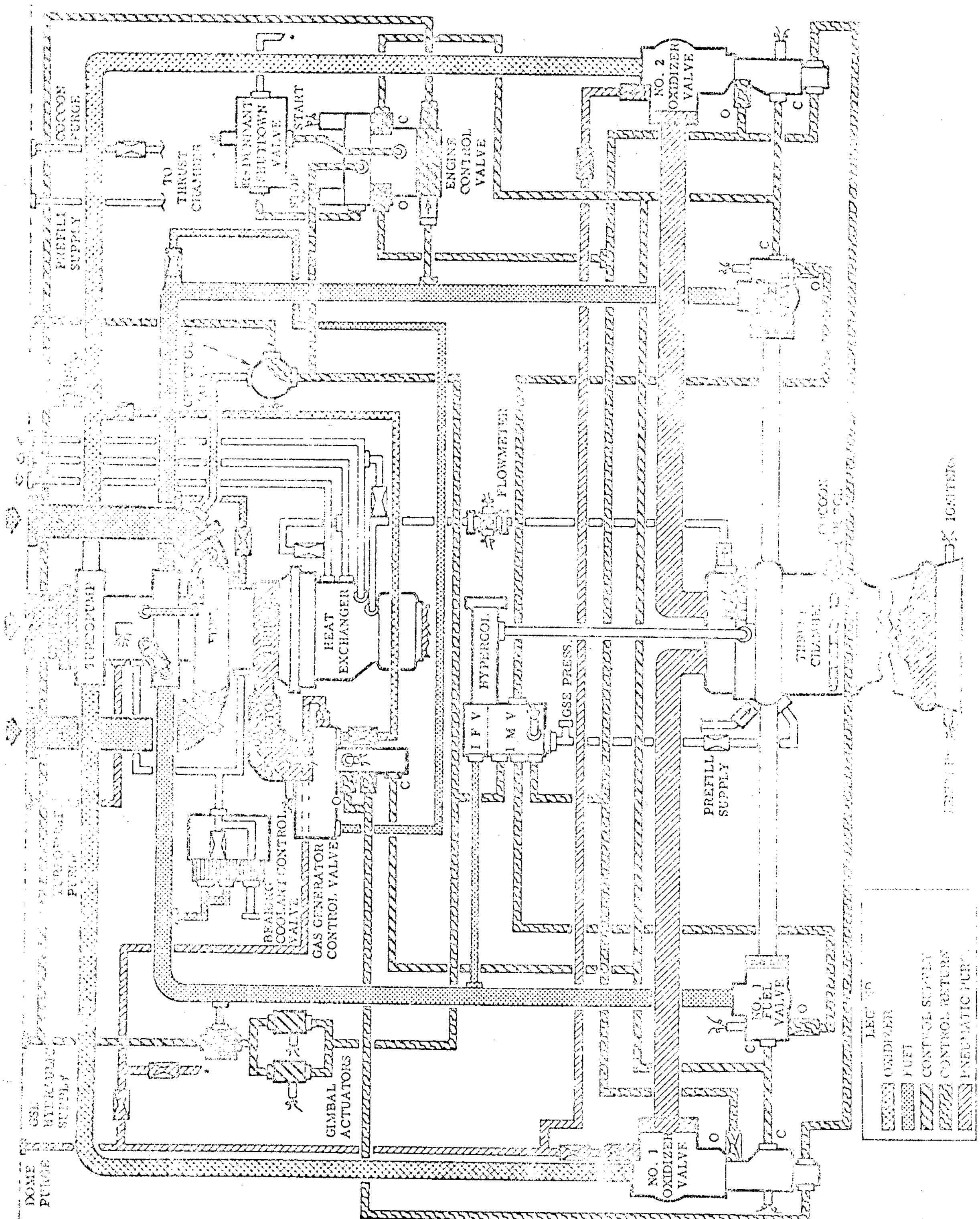


Figure 1-56. Engine Cutoff

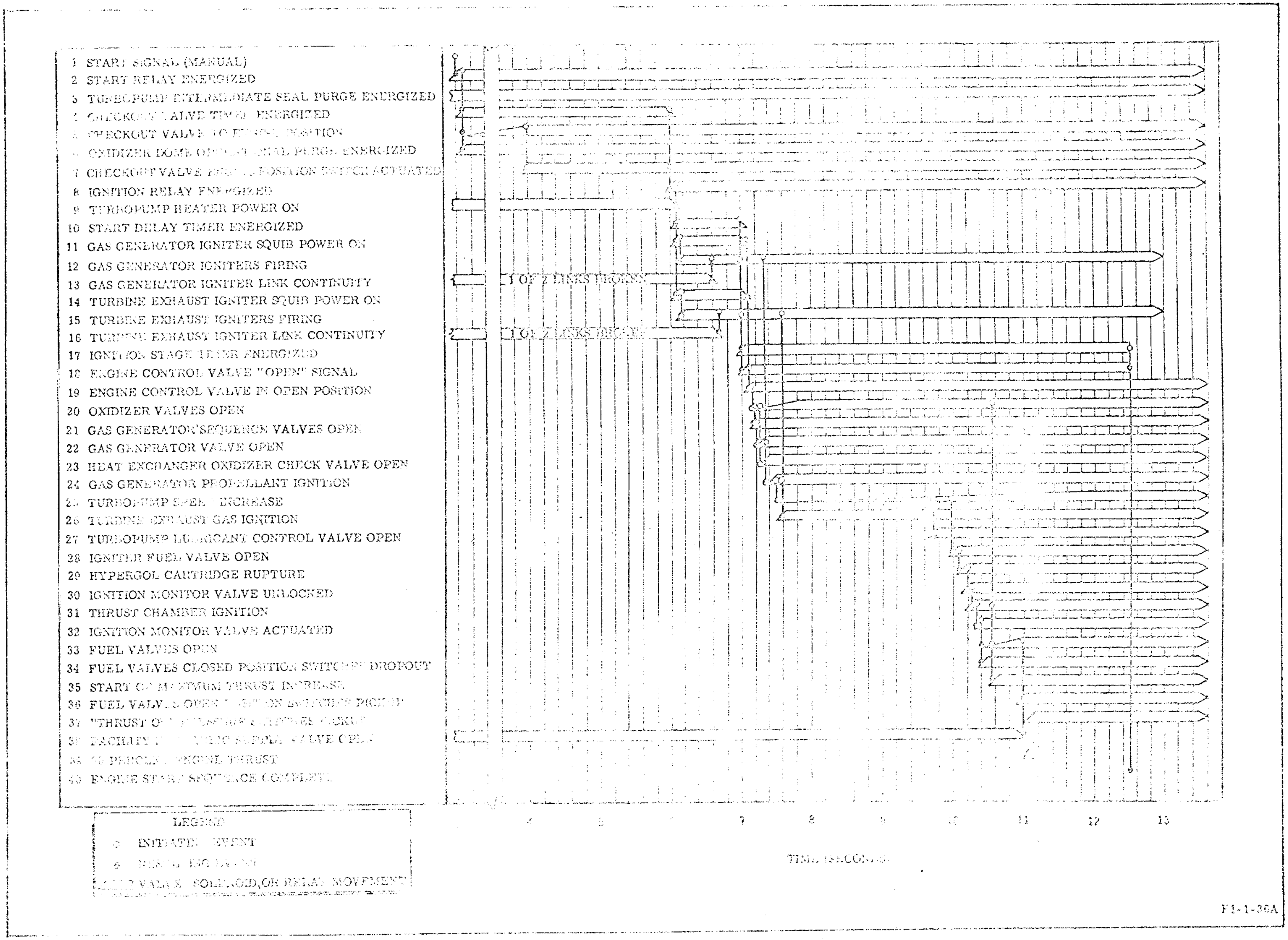


Figure 1-57. Engine Start Sequence Flow (Typical)

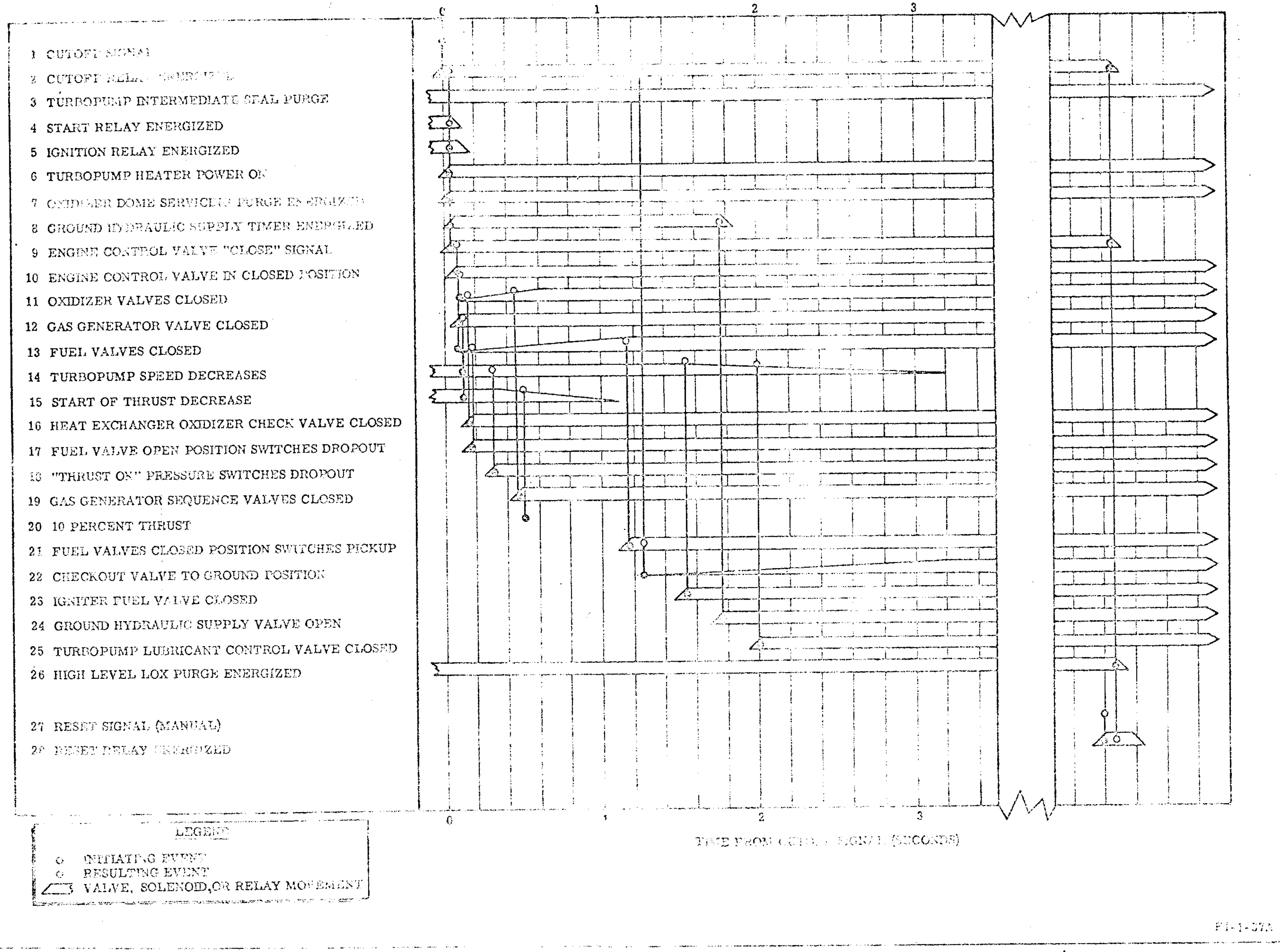


Figure 1-58. Engine Cutoff Sequence Flow (Typical)

1-134. F-1 ENGINE FLOW.

1-135. The following describes F-1 engine flow (figure 1-59) and events that take place from the time of Customer acceptance of the engine at Rocketdyne, Canoga Park, through Apollo/Saturn V launch at Kennedy Space Center (KSC). After offical acceptance of the engine (signing of DD Form 250), modifications may be made or maintenance tasks may be performed, with Customer approval, before shipment. The engine, nozzle extension, and loose equipment are shipped to the Michoud Assembly Facility (MAF) by either truck or ship. (Thermal insulation (TIS) is shipped to MAF by truck.) At MAF the engine is inspected and then assigned to a stage, designated as a spare, or left unassigned. Spare engines and unassigned engines are processed to a specific condition and placed in storage until needed. The normal flow of assigned engines consists of installing loose equipment and TIS brackets, performing modifications and maintenance, and installing the thrust vector control system on outboard engines. Single-engine checkout is performed, wrap-around ducts and hoses are installed, and the engines are installed in the stage. The stage and nozzle extensions are then shipped to the Mississippi Test Facility (MTF) by barge.

1-136. The stage is installed in the static test stand at MTF where the engines are inspected, and nozzle extensions, slave hardware, and static test instrumentation are installed. A pre-static checkout of the stage is performed, followed by a static test, to determine stage acceptability and flight readiness. After a successful stage static test, the engines are inspected, test data is reviewed, and the turbopumps are preserved. The nozzle extensions, slave hardware, and static test instrumentation are removed; then the stage is removed from the test stand, and the stage and nozzle extensions are shipped to MAF by barge. During normal stage flow at MAF, the installed-engines are inspected and refurbished; then a post-static checkout and a pre-shipment (to KSC) inspection are performed. The stage may be stored at MAF after engine refurbishment, depending on the stage schedule. The stage, nozzle extensions, loose equipment, and TIS are shipped to KSC by barge.

1-137. At KSC the stage is erected onto the Launch Umbilical Tower (LUT) in the Vertical Assembly Building (VAB), where a visual inspection is performed, loose equipment is installed, modifications are made, and maintenance tasks are performed. Stage and engine leak and functional tests are performed, and final installation of the TIS is completed. While the first stage is being prepared, other tasks are being done to prepare the remaining stages and modules, and the spacecraft, to mate and assemble them into the complete Apollo/Saturn V Vehicle. The vehicle and mobile launcher are then moved from the VAB to the launch pad on the crawler transporter, where launch preparations and final checkouts are performed. With all preparations complete and all systems ready, the Apollo/Saturn V is launched. After launch, a post-flight data evaluation is made, to determine that the S-IC

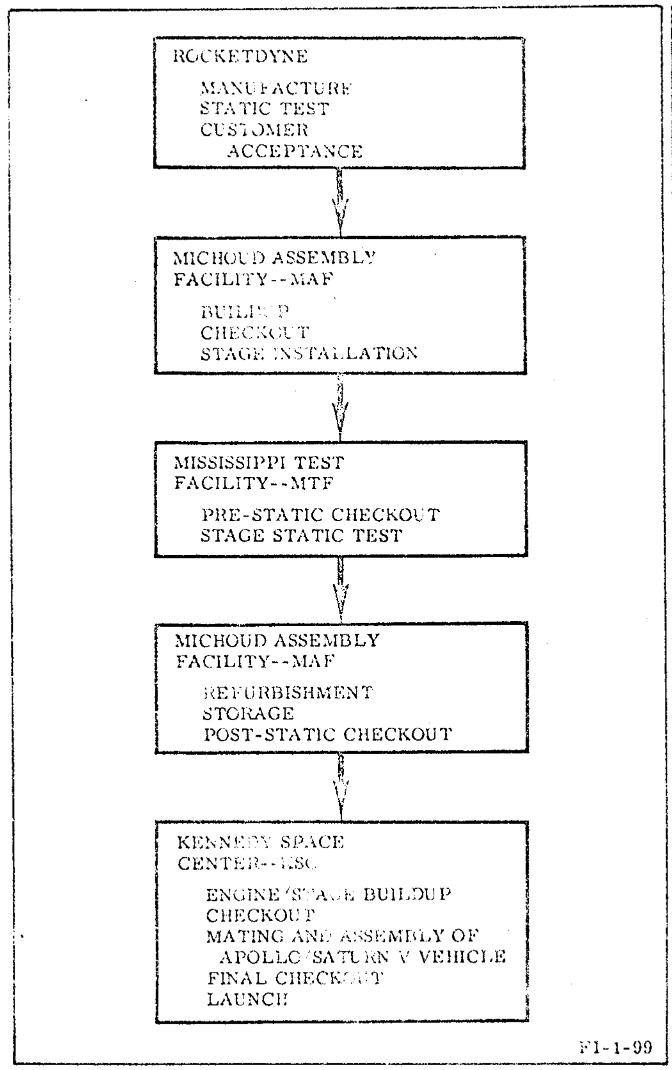


Figure 1-59. F-1 Engine Flow

stage engines operated within the specified values during vehicle launch.

1-138. ENGINE FLOW BEFORE FIELD DELIVERY.

1-139. CUSTOMER ACCEPTANCE INSPECTION.

1-140. Customer acceptance inspection is performed when Contractor engine activity at Canoga Park is complete. The Customer reviews all documentation including Component Test Records, Engine Buildup Records, Engine Test Records, and Engine Acceptance Test Records in the Engine Log Book. The Customer verifies that the engine configuration information on the engine MD identification plate corresponds to that listed in the Engine Log Book, and upon acceptance of all records and documentation, signs DD Form 250, which constitutes official acceptance of the engine by the Customer.

1-141. POST-DD250 MAINTENANCE OR MODIFICATION.

1-142. If required before field delivery of an engine, post-DD250 maintenance or modification, as required by Engineering Change Proposals (ECPs) and Engine Field Inspection Requests (EFIRs) can be done at Rocketdyne with Customer approval. Upon completion of maintenance or modification, the Engine Log Book is updated, and the engine is accepted by the Customer.

1-143. ENGINE SHIPMENT TO MAF.

1-144. The engine, nozzle extension, and loose equipment is shipped to MAF by truck or ship as directed by the Customer. See figure 1-60. Detailed requirements for shipping the engine are in R-3896-9. Detailed requirements describing the use of handling equipment are in R-3896-3.

1-145. PREPARATION FOR SHIPMENT.

1-146. Preparation for shipment at the Contractor's facility consists primarily of removing the engine from buildup and test equipment, installing the engine and nozzle extension in shipping equipment, and packaging the loose equipment. Engine Rotating Sling G4050 is installed on the engine and a facility hoist lifts the sling and rotates the engine from vertical to the lowered (shipping) position, or from horizontal to the lowered position. A gaseous nitrogen purge is applied to the oxidizer pump seal during the time the engine is being rotated to the horizontal or lowered position. The engine is then secured on Air Transport Engine Handler G4044 in the lowered position and the sling removed. If the engine is to be shipped cross-country by truck, the turbopump shaft preload fixture is installed. A check is then made to make sure that Thrust Chamber Throat Security Closure G4089 is installed, that all desiccant is correctly secured, that the humidity range is acceptable, that openings are covered with suitable closures, and that the gimbal bearing is immobilized with Gimbal Bearing Lock G4059. The frame and Engine Cover G4047 are installed on the engine with the necessary forms sealed in the security pouch. Using a facility hoist and Engine Handler Sling G4052, the nozzle extension is installed on Nozzle Extension Handling Fixture G4080 and the loaded nozzle extension installed on Handling Adapter G4081. Because of shipping regulations governing transportation of ignition devices, the engine hypergol cartridge and pyrotechnic igniters are not shipped with the engine.

1-147. SHIPPING BY TRUCK.

1-148. Trucks are used to transport the engine, nozzle extension, and loose equipment, cross-country or to and from dock sites. Using a facility hoist and Engine Handler Sling G4052, the handler-installed engine and loaded nozzle extension (installed on the handling adapter) are loaded and secured on a low-bed, air-ride-equipped trailer. Loose equipment is packaged in boxes, loaded by forklift, and secured. For cross-country shipping, a calibrated impact recorder is installed on the handler. A truck transport checklist is used as a guide to verify that specified procedures are performed before truck departure and during cross-country shipping.

1-149. SHIPPING BY SHIP.

1-150. The engine, nozzle extension, and loose equipment are delivered to the ship by truck. The low-bed trailer is positioned on the ship's deck. Using a mobile crane, Engine Handler Sling G4052, and tractor, the Handler-installed engine is removed from the trailer, placed on the cargo deck; then moved forward and

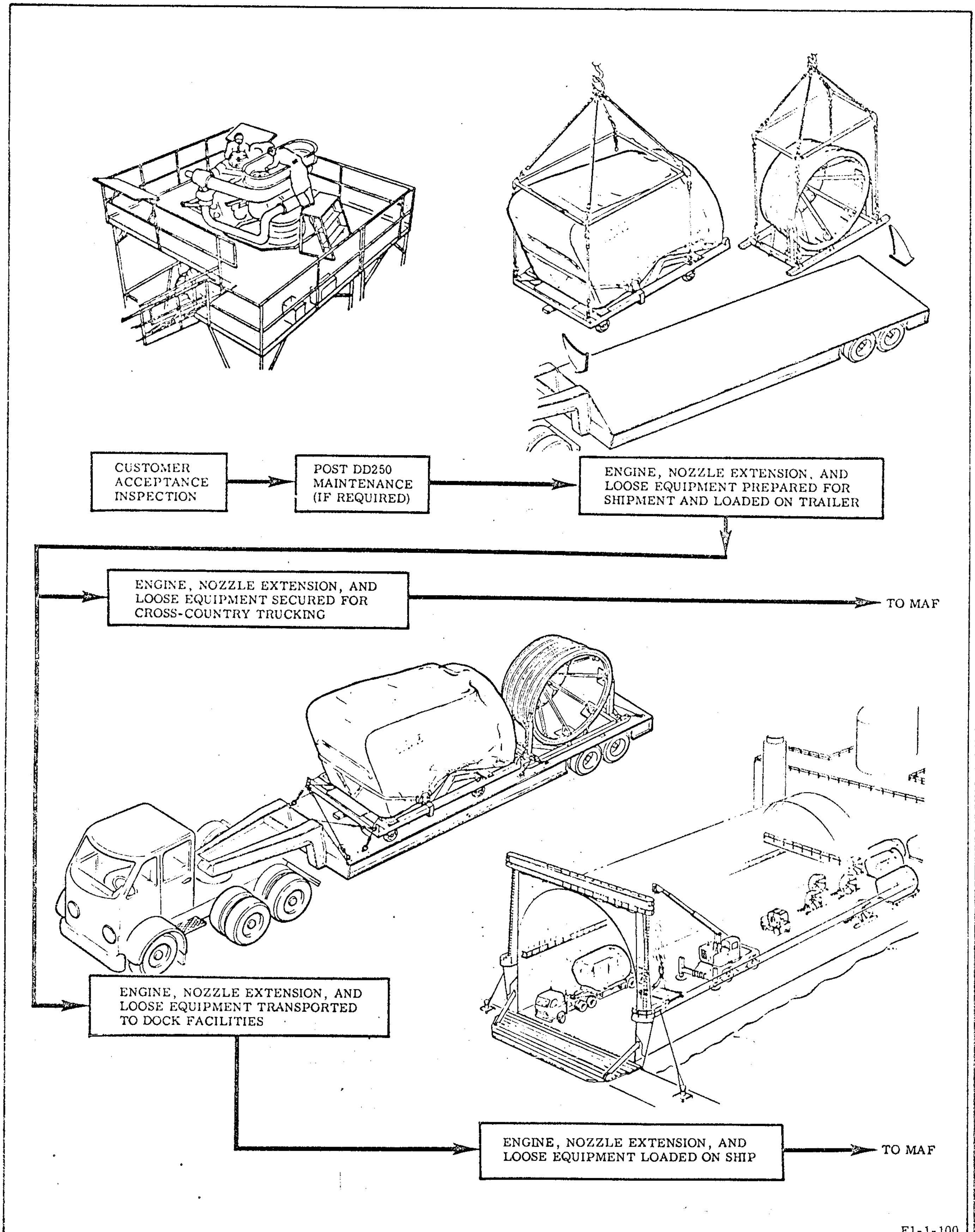


Figure 1-60. Engine Shipment to MAF

secured. The nozzle extension and loose equipment are removed from the trailer by mobile crane or forklift and secured to the cargo deck. The water transport checklist is used as a guide to verify that specified procedures are performed before departure, in transit, and after docking.

1-151. RECEIVING ENGINE AT MAF.

1-152. The Stage Contractor receives the engine and is responsible for engine flow at MAF. See figure 1-61. Detailed requirements for engine receiving by truck and ship are in R-3896-9. Detailed requirements describing the use of engine handling equipment are in R-3896-3.

1-153. RECEIVING BY TRUCK.

1-154. Engines, nozzle extensions, and loose equipment received by cross-country truck or by truck from the MAF dock are delivered to the Manufacturing Building where the equipment is visually inspected for shipping damage. If arriving at MAF by cross-country truck, the arrival time and date are recorded on the impact recorder chart. Using the facility hoist and Engine Handler Sling G4052, the handler-installed engine and nozzle extension are moved from the trailer to the floor. Loose equipment is removed from the trailer using a forklift. The nozzle extension is routed to the nozzle extension storage area, and loose equipment is routed to the Engine Support Hardware Center. The engine is routed to the engine area or to the bonded storage area (if unassigned), where the impact recorder and turbopump preload fixture are removed (if installed) and returned to Canoga Park.

1-155. RECEIVING BY SHIP.

1-156. When the ship arrives at the MAF dock, a tug, mobile crane, and low-bed trailer are positioned on the ship's cargo deck for the off-loading procedure. Using Engine Handler Sling G4052 and the mobile crane, the engine and nozzle extension are loaded and secured on the low-bed trailer. The loose equipment is loaded on the trailer by forklift. The trailers are moved into the Manufacturing Building, where the engine, nozzle extension, and loose equipment are inspected for shipping damage. Engine receiving then proceeds as described in paragraph 1-153.

1-157. UNASSIGNED-ENGINE FLOW AT MAF.

1-158. Unassigned-engine flow at MAF pertains to unassigned and spare engines. Upon receipt at the Manufacturing Building, unassigned engines are inspected for shipping damage, moved to the bonded storage area, inspected, and stored until scheduled for modification and/or assigned to a stage. Spare engines are processed through buildup and single-engine checkout, moved to the bonded storage area, and stored in a standby condition in case engine replacement is required. Single-engine checkout is required for all engines in storage over six months. If any discrepancies are observed during engine flow at MAF, Engine Contractor personnel perform unscheduled maintenance and repair or replace discrepant hardware on the engine. Discrepant hardware removed from the engine is routed to the CM&R area, where it is repaired and tested.

1-159. STORAGE RECEIVING INSPECTION.

1-160. Unassigned engines are visually inspected in the bonded storage area. The engine cover is removed, and the engine inspected for damage, corrosion, residual fluid on exterior surfaces, and surface wetting on the hydraulic control system exterior. It is verified that specified areas of the engine are coated with corrosion preventive, that humidity indicators indicate blue, and that line markings are correct. The turbopump preservation status is checked in the Engine Log Book, and the turbopump is serviced if required. The engine cover is reinstalled. Detailed inspection requirements for engines in storage are in R-3896-11.

1-161. ENGINE FLOW AT MAF. (See figure 1-62.)

1-162. When an uninstalled engine is received in the engine area, it is removed from Air Transport Engine Handler G4044, rotated to the vertical position, and placed on Engine Handling Dolly G4058 using Engine Rotating Sling G4050 and the facility hoist. The engine is then moved into a workstand where receiving inspection and engine buildup are accomplished. After engine buildup, the engine is placed into a test stand for single-engine checkout and installation of wrap-around lines. The engine is then removed from the test stand, rotated to the horizontal position, and installed on Engine Handler G4069. The oxidizer pump seal is purged with gaseous

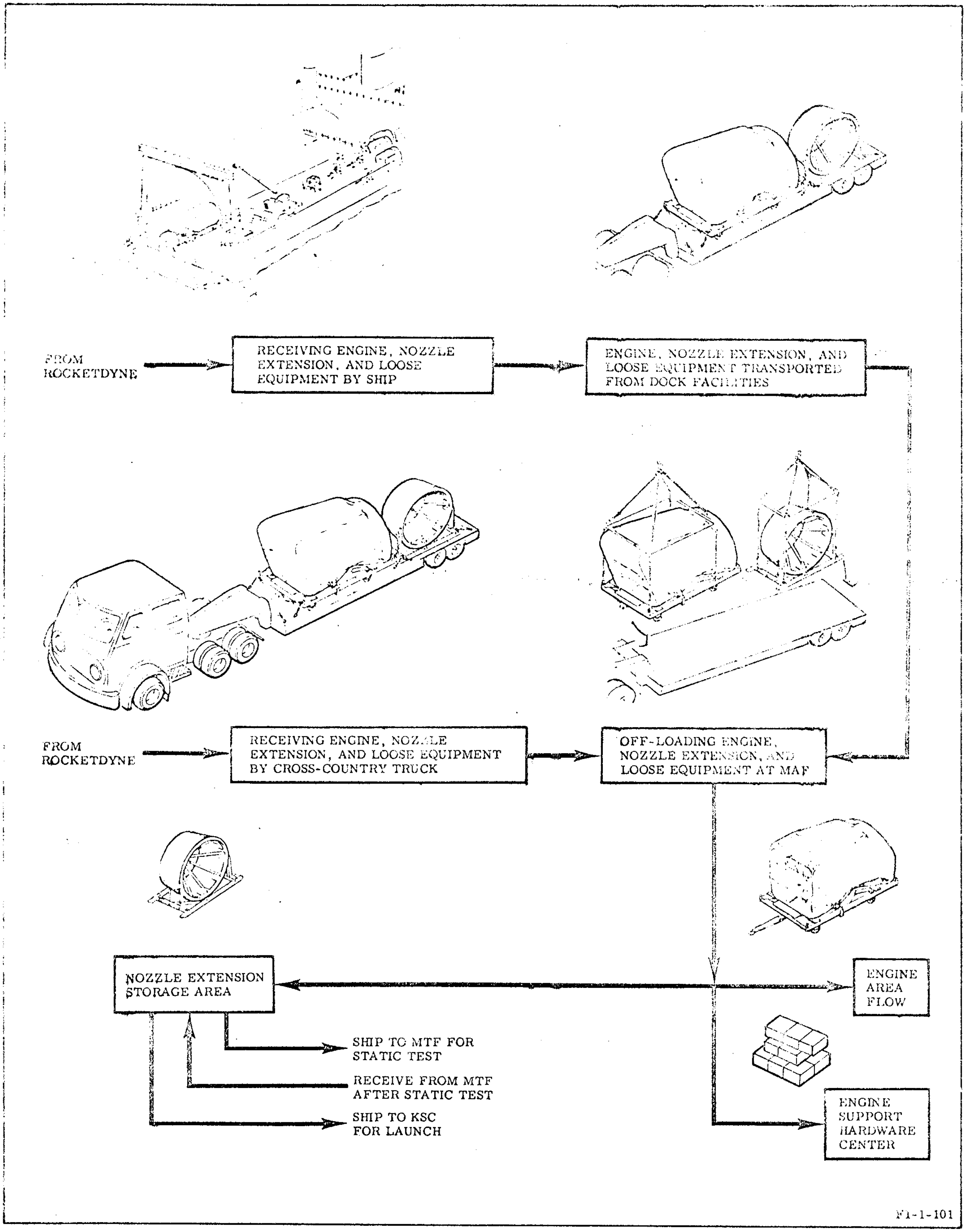


Figure 1-61. Receiving Engine at MAF

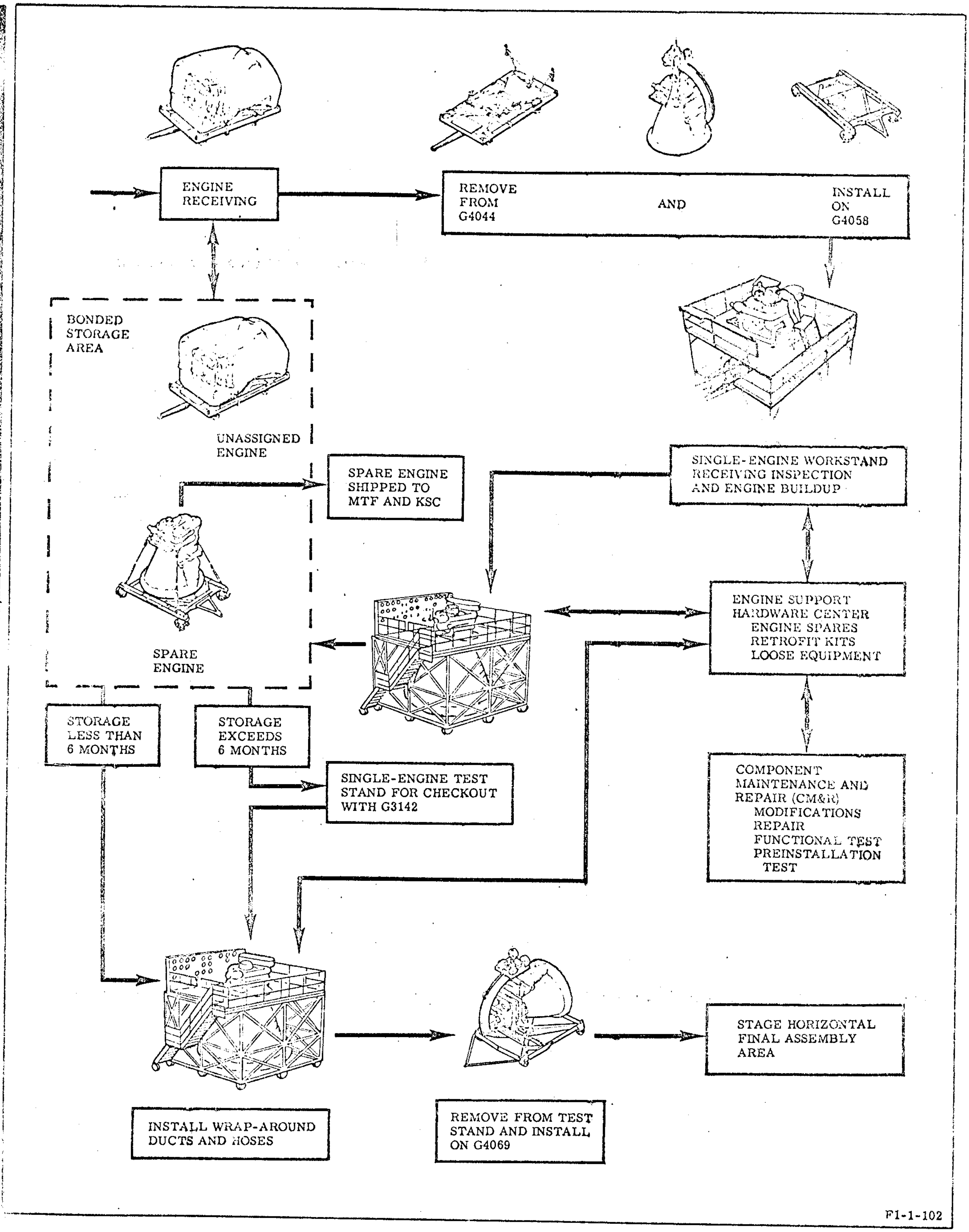


Figure 1-62. Engine Flow at MAF

nitrogen during engine rotation to the horizontal position and for 30 minutes (minimum) thereafter. The engine is moved to the Stage Horizontal Final Assembly Area, where the engine is prepared for installation, installed in the stage, and inspected in preparation for shipment to MTF. Engine modifications are made as required during engine flow at MAF. If any discrepancies are observed, Engine Contractor personnel perform unscheduled maintenance, and repair or replace hardware on the engine. Discrepant hardware removed from the engine is routed to the CM&R area, where it is repaired and tested. Detailed requirements describing the use of engine handling equipment are in R-3896-3.

1-163. RECEIVING INSPECTION.

1-164. After installation in the single-engine workstand in the engine area of the Manufacturing Building, each assigned engine undergoes an overall visual receiving inspection. The engine is visually inspected for damage, corrosion, and missing equipment; for evidence of fluid in drain line exits or on the engine exterior; and for surface wetting on the hydraulic control system exterior. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, line markings are correct, humidity indicators indicate blue, and there are no voids in the turbopump housing cavity filler material. A clean polyethylene bag is installed on the fuel overboard drain line, the turbopump preload fixture is removed, and orifice sizes and serialized components are checked against those listed in the Engine Log Book. Detailed inspection requirements for engines received at MAF are in R-3896-11.

1-165. ENGINE BUILDUP, MODIFICATION, AND MAINTENANCE.

1-166. LOOSE EQUIPMENT INSTALLATION. Loose equipment that does not interfere with single-engine checkout is installed during engine buildup. The electrical cable support post is installed only on engines assigned to the outboard positions. The interface panel-to-oxidizer inlet insulation seal is installed on all engines. Wrap-around ducts and hoses are not installed at this time.

1-167. THERMAL INSULATION BRACKETRY INSTALLATION. The field-installed thermal insulation bracketry is normally stored at MAF until installation on the engine. All brackets are installed except for the bracket that attaches to the engine handling bearing. The engine handling bearing is an attach point for securing the engine onto Engine Handler G4069; therefore, the bracket is installed after the engine is installed on the stage. Requirements for installing thermal insulation brackets are in R-3896-6.

1-168. MODIFICATION AND MAINTENANCE. Modifications are made and maintenance tasks are performed during engine buildup, whenever possible. Engine modifications and special inspections consist of incorporating retrofit kits, as a result of Engineering Change Proposals (ECPs), and implementing Engine Field Inspection Requests (EFIRs). Engine maintenance involving component removal and replacement or turbopump disassembly, if required, is done in the engine workstands. Component modification, repair, and functional testing are done in the environmentally controlled CM&R area.

1-169. THRUST VECTOR CONTROL SYSTEM INSTALLATION. The thrust vector control system is installed by the Stage Contractor on engines assigned to the outboard positions. This system consists of two gimbal actuators, hydraulic supply and return lines, and a hydraulic filter manifold.

1-170. SINGLE-ENGINE CHECKOUT.

1-171. Single-engine checkout is done after receiving inspection and after engine buildup tasks are completed. The engine is installed in the test stand, where the ignition monitor valve sense tube is disconnected, Thrust Chamber Throat Security Closure G4089 removed, and Thrust Chamber Throat Plug G3136 installed. All connections are made between the engine and Engine Checkout Console G3142; facility electrical, pneumatic, and hydraulic sources are applied to the console; and the console is prepared for operation. Electrical system function and timing tests, a turbopump torque test, pressure tests, valve timing tests, and leak and function tests are done in accordance with the detailed requirements in R-3896-11. Upon completion of engine checkout, the ignition monitor valve sense tube is connected, Thrust Chamber Throat Plug G3136 removed, and Thrust Chamber Throat Security Closure G4089 installed.

1-172. WRAP-AROUND DUCT AND HOSE INSTALLATION.

1-173. The loose-equipment wrap-around ducts and hoses are installed on the engine in the test stand after single-engine checkout. The helium, GOX, and hydraulic wrap-around ducts and the purge and prefill hoses are installed and connected to flanges used for test setups during engine testing. The ducts and hoses are alined using alinement tool T-5041233 and supported with support set T-5046440 to prevent movement until the engine is installed in the stage and interface connections are completed. The engine is then removed from the test stand. Detailed requirements for installing and alining wrap-around ducts and hoses are in R-3896-3.

1-174. ENGINE INSTALLATION AT MAF. (See figure 1-63.)

1-175. PREPARATION FOR ENGINE INSTALLATION. The engine is rotated to the horizontal position and installed on Engine Handler G4069 using Engine Rotating Sling G4050 and the facility hoist. The oxidizer pump seal is purged during engine rotation to the horizontal position and for 30 minutes (minimum) thereafter. After removing the interface panel access doors, the oxidizer and fuel inlet covers are removed, the inlets inspected for contamination, the oxidizer inlet screen and seal secured in place, and the inlets covered with Aclar film. The fuel overboard drain system is isolated using clean polyethylene bags. The gimbal boot cover is removed, and it is verified that the gimbal bearing locks are installed, the electrical cable support post is installed on engines assigned to outboard positions, and the engine gimbal wrap-around lines are installed and adequately supported. When ready for installation in the stage, the engine is moved to the Stage Horizontal Final Assembly Area and positioned under a mobile hoist (A-frame). Thrust Chamber Throat Security Closure G4089 is removed and the thrust chamber inspected. The engine horizontal installation tool is suspended from the mobile hoist, prepared for engine installation, and then installed in the thrust chamber. The engine is then removed from Engine Handler G4069 and raised and rotated to the position required for engine installation. Detailed requirements for fuel overboard drain system isolation and engine preparation for installation are in R-3896-11.

1-176. ENGINE INSTALLATION. (See figure 1-63.) When preparations for engine installation are completed and the engine is correctly positioned in the stage, the engine gimbal bearing is mated and secured to the stage attach point. On the outboard engines, the gimbal actuators are secured to the stage actuator locks, while on the inboard engines, the stiff arms are secured to the actuator locks. Gimbal bearing locks are removed, and the gimbal boot is reinstalled on the gimbal bearing. The engine horizontal installation tool is removed from the thrust chamber after the engine is secured to the stage; then the Thrust Chamber Throat Security Closure G4089 is installed. Aclar film is removed from engine oxidizer and fuel inlets, fuel inlet seals and screens are installed, and stage ducting is connected to the engine inlets. The interface electrical connectors and stage pressure switch checkout supply line are connected at the interface panel, and the wrap-around ducts and hoses are connected to the stage. The thermal insulation bracket that attaches to the engine handling bearing is installed as specified in R-3896-6. Detailed requirements for installing the engine are in R-3896-11.

1-177. MANUFACTURING INSTALLATION VERIFICATION. When engine installations and stage assembly are completed, the Stage Contractor performs a manufacturing installation verification. This verification consists of a gaseous nitrogen leak test of the engine interface connections and stage systems.

1-178. INSTALLED-ENGINE INSPECTION BEFORE STAGE SHIPMENT TO MTF.

1-179. The installed-engine inspection before shipment to MTF is made after the stage assembly and verification tests are complete. Each engine is visually inspected for damage, corrosion, and missing equipment; for evidence of fluid in drain line exits, fluid on the engine exterior; and for surface wetting on the hydraulic control system exterior. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, line markings are correct, the humidity indicator in the thrust chamber throat security closure indicates blue, and there are no voids in the turbopump housing cavity filler material. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags

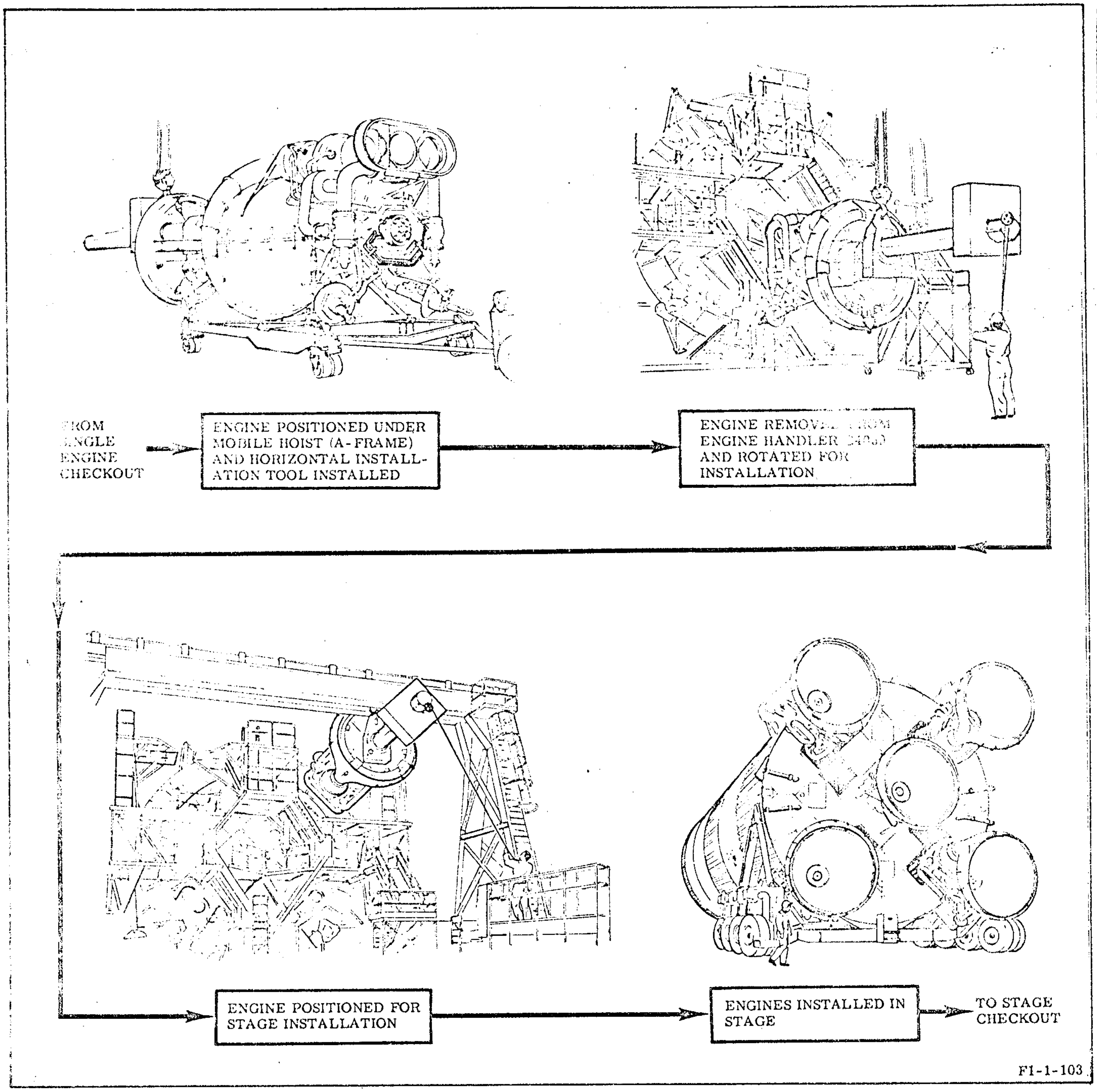


Figure 1-63. Engine Installation at MAF

are emptied and the quantity of fluid is measured. The turbopump preservation status is checked in the Engine Log Book, and the turbopump is serviced if required. A final updating of the Engine Log Book is made before engine shipment to MTF. Detailed procedures for inspecting the installed engine before shipment to MTF are in R-3896-11.

1-180. STAGE SHIPMENT TO MTF. (See figure 1-64.)

1-181. When installed-engine inspection is complete, the forward stage cover and engine covers are installed, the workstands and platforms are rolled away from the engines, a tractor is connected to the stage transporter,

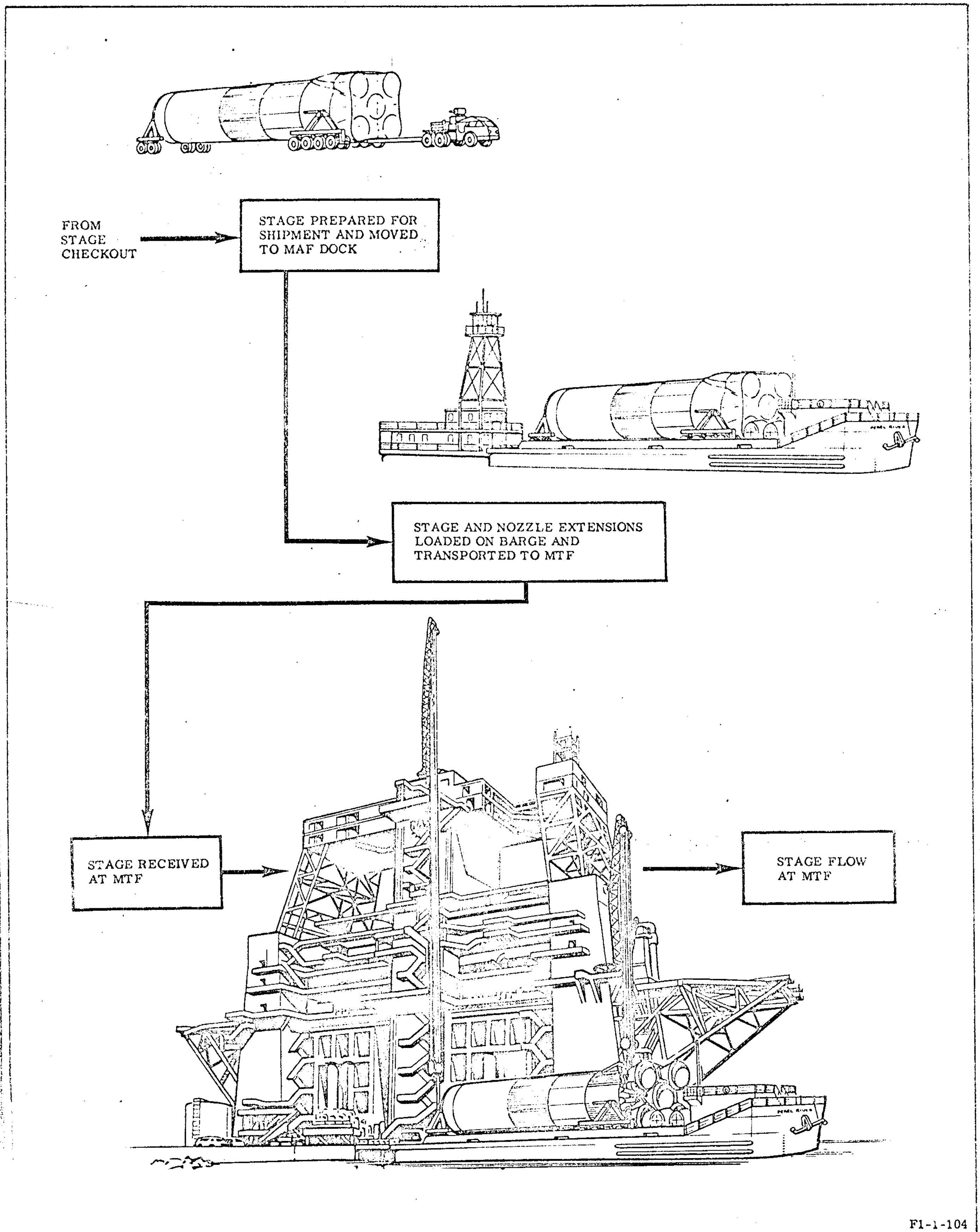


Figure 1-64. Stage Shipment to MTF

and the stage is pulled to the MAF dock. The stage is loaded onto the barge and secured. The nozzle extensions are loaded on low-bed trailers, towed to the MAF dock, loaded on the barge using a mobile hoist, and secured. The barge is then moved to MTF by tug.

1-182. STAGE FLOW AT MTF. (See figure 1-65.)

1-183. The stage is received at MTF and installed in the test stand. The engine covers are removed, and receiving inspection is performed. The nozzle extensions, slave hardware (normally stored at MTF), and MTF static test instrumentation are installed; then a pre-static checkout is performed. Thermal insulation is not required for static test, therefore it is not installed. Engine maintenance is done and modifications are made as required during engine flow at MTF. Upon completion of pre-firing preparations, the static firing test is performed. After static test, the engines are inspected; the test instrumentation, slave hardware, and nozzle extensions are removed; a pre-shipment inspection is performed; and the stage and nozzle extensions are removed from the test stand and loaded on the barge for return to MAF.

1-184. STAGE INSTALLATION IN TEST STAND.

1-185. When the stage arrives at MTF, the barge is docked next to the test stand. Test stand overhead cranes are attached to the forward and aft ends of the stage; the stage is lifted clear of the stage transporter and barge, rotated to the vertical position, and positioned into the test stand. During rotation to the vertical position, the thrust chamber and exhaust manifold are monitored for fuel leakage. The stage is secured to the test stand with mechanical holddowns; stage/facility propellant, hydraulic, pneumatic, and electrical connections are secured; and engine covers and engine oxidizer and fuel inlet screens are removed.

1-186. ENGINE RECEIVING INSPECTION.

1-187. After the stage is installed in the test stand, the engines undergo an overall visual receiving inspection. Each engine is inspected for damage, corrosion, and missing equipment and for evidence of fluid in drain line exits. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, the engine soft goods installed life is within specified limits, and there are no voids in the turbopump housing cavity filler material. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. Engine orifice sizes and serialized components are checked against those listed in the Engine Log Book. Detailed inspection requirements for installed engines received at MTF are in R-3896-11.

1-188. INSTALLATION OF NOZZLE EXTENSIONS, SLAVE HARDWARE, AND MTF STATIC TEST INSTRUMENTATION.

1-189. The nozzle extensions, slave hardware, and MTF static test instrumentation are installed on the engines after the stage is installed in the test stand and after receiving inspection. Using Engine Handler Sling G4052 and overhead cranes the nozzle extension is removed from the barge and from Nozzle Extension Handling Fixture G4080 and Handling Adapter G4081 and placed on Engine Vertical Installer G4049 on the lower stand work platform. The installer, with nozzle extension, is positioned below the engine; then the nozzle extension is installed on the engine, and the installer lowered. The polyethylene bags are removed from the fuel overboard drain system, and the slave fuel, oxidizer, and nitrogen overboard drain lines are installed. The slave igniter harness and MTF static test instrumentation are then installed and connected. Detailed installation requirements are in R-3896-11. Detailed nozzle extension handling requirements are in R-3896-9.

1-190. STAGE PRE-STATIC CHECKOUT.

1-191. The stage pre-static checkout is performed on all engine and stage systems. Immediately preceding pre-static checkout, Thrust Chamber Throat Security Closure G4089 is removed and Thrust Chamber Throat Plug G3136 is installed. The checkout consists of electrical hydraulic, and pneumatic leak and function tests. A simulated static test, which simulates stage preparation, engine start, ignition, mainstage, and cutoff sequencing, is performed to verify stage acceptability for static test. Detailed pre-static checkout requirements are in R-3896-11.

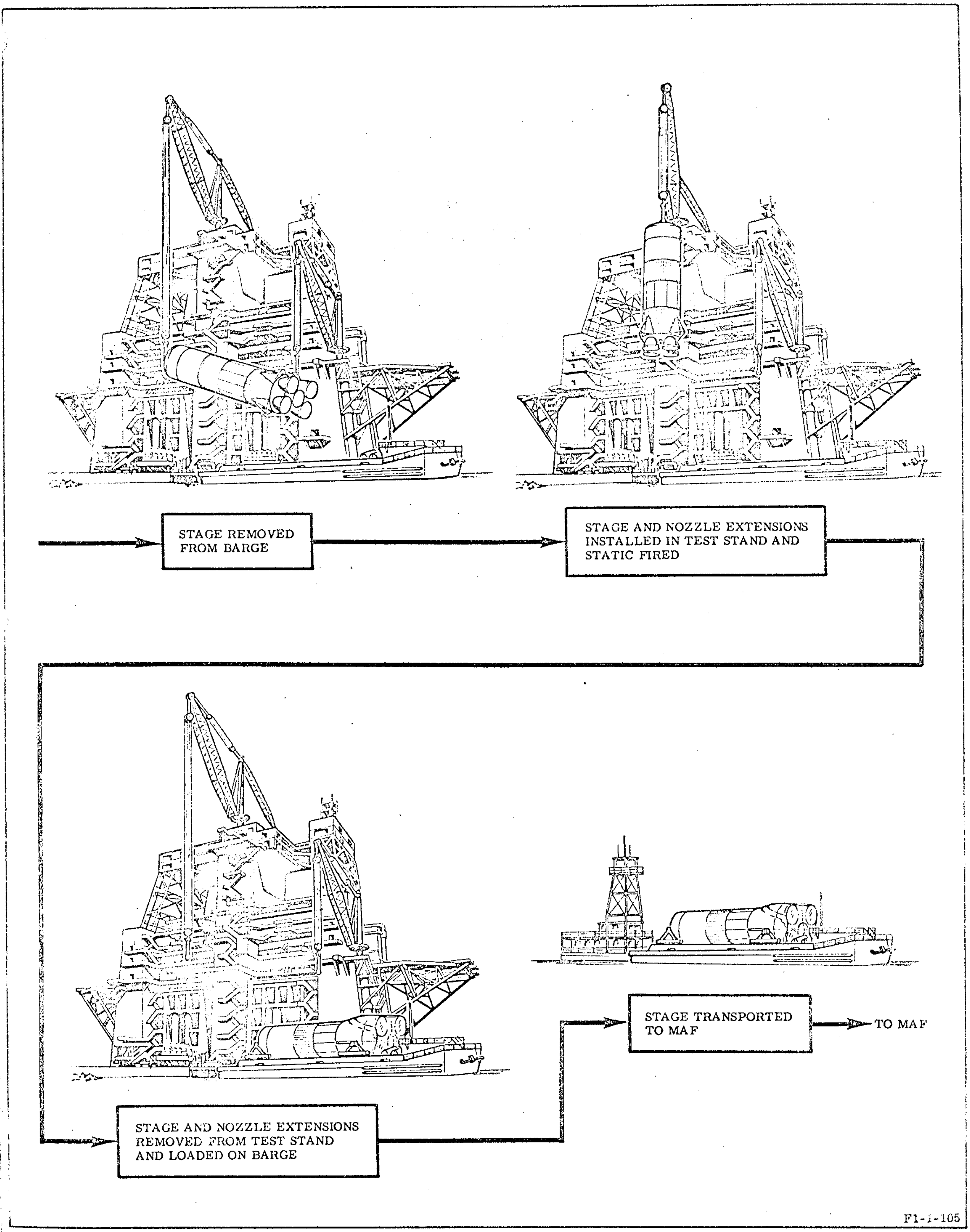


Figure 1-65. Stage Flow at MTF

1-192. STATIC TEST.

1-193. When all required checkout procedures, modifications, and maintenance are completed, and the Thrust Chamber Throat Plug G3136 is removed, the hypergol cartridge and pyrotechnic igniters are installed and checked out and the test area is cleared in readiness for static test. A 125-second, uninterrupted-duration stage static test is made to checkout all electrical-electronic, propulsion, mechanical, pressurization, propellant, and control systems that function during actual countdown, launch, and flight. Measurements of the static test are recorded and processed to determine stage acceptability and flight readiness. The engine start for the stage is a 1-2-2 sequence: the center engine starts first, and the remaining outboard engines start in opposed groups of two. The engine cutoff is a 3-2 sequence: the center engine and two opposite outboard engines cut off first; then the remaining two outboard engines cut off. The single-engine start and cutoff sequence flows are in figures 1-57 and 1-58.

1-194. ENGINE INSPECTION AFTER STATIC TEST.

1-195. The engine and nozzle extension are inspected visually after static test to verify that damage did not occur during the test. Detailed inspection requirements are in R-3896-11 and include inspecting for exterior damage and missing aluminum tape between thrust chamber exhaust manifold and thrust chamber tubes; inside of thrust chamber for tube and injector damage, injector contamination, and liquid leakage. Other inspections are for tension tie deformation, bent or broken studs, nozzle extension for carbon deposits around flange area, and internal damage and erosion.

1-196. STATIC TEST DATA REVIEW.

1-197. The static test data is reviewed after static test to determine that the engine is operating within specified limits. Test instrumentation readings are examined to detect abnormalities, sudden shifts, oscillations, or performance near the minimum or maximum limits.

1-198. TURBOPUMP PRESERVATION.

1-199. The turbopump is preserved within 72 hours after static test. After removing fluid through the turbopump No. 3 bearing drain line, the turbopump bearings are purged with gaseous nitrogen, and five gallons of preservative oil is supplied to the bearings while the turbopump is slowly rotated. The fluid is then drained through the No. 3 bearing drain line, and the bearings are again purged with gaseous nitrogen. The preservation date is recorded in the Engine Log Book.

1-200. REMOVAL OF NOZZLE EXTENSIONS SLAVE HARDWARE, AND MTF STATIC TEST INSTRUMENTATION.

1-201. Engine Vertical Installer G40[illegible] is positioned below the [illegible] nozzle extension removed from the engine and lowered onto the installer. Using Engine Handler Sling G4052 and overhead cranes, the nozzle extension is removed from the installer, installed on Nozzle Extension Handling Fixture G4080, and the loaded nozzle extension installed on Handling Adapter G4081. The slave hardware, consisting of fuel overboard drain lines and the igniter harness, is removed, cleaned, tested, and repaired or replaced, as required, for reuse during the next static test. The fuel overboard drain system is isolated using clean polyethylene bags. The expended igniters and hypergol cartridge are removed. The MTF static test instrumentation is disconnected and removed and the instrumentation ports plugged immediately by incorporating the applicable retrofit kit specified in Modification Instruction R-5266-391 (ECP F1-391). The Thrust Chamber Throat Security Closure G4089 is installed. Detailed removal requirements are in R-3896-11. Detailed nozzle extension handling requirements are in R-3896-9.

1-202. INSTALLED-ENGINE INSPECTION BEFORE STAGE SHIPMENT TO MAF.

1-203. The engine is inspected before shipment to MAF and after all post-static-test tasks are complete. Each engine is visually inspected for damage, corrosion, and missing equipment; for evidence of fluid in drain line exits or on the engine exterior; and for surface wetting on the hydraulic control system exterior. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, line markings are correct, the humidity indicator in the thrust chamber throat security closure indicates blue, and there are no voids in the turbopump housing cavity filler material. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. All engine protective closures are installed upon completion of visual inspection. It is verified that the humidity indicator in the thrust chamber throat security closure indicates blue at the time of shipment. Detailed inspection requirements are in R-3896-11.

1-204. STAGE REMOVAL FROM TEST STAND.

1-205. After engine visual inspection, the engines and stage are prepared for removal from the test stand. The engine and stage covers are installed; stage/facility propellant, hydraulic, pneumatic, and electrical connections are disconnected; and mechanical holddowns are removed. Test stand overhead cranes are attached to the forward and aft ends of the stage; the stage is lifted clear of the test stand, rotated to the horizontal position, and installed on the stage handler on the barge. The oxidizer pump seal is purged during engine rotation to the horizontal position and for 30 minutes (minimum) thereafter. The nozzle extensions, installed on Nozzle Extension Handling Fixtures G4080 and Handling Adapters G4081, are removed by overhead crane and loaded on the barge. The stage transporter and nozzle extensions are secured on the barge for shipment. A final updating of the Engine Log Book is made before shipment to MAF.

1-206. STAGE SHIPMENT TO MAF.

1-207. The barge, containing the stage and nozzle extensions, is moved from MTF to MAF by tug. Upon arrival at the MAF dock, a tractor is connected to the stage transporter, and the stage is pulled from the barge and towed to the Stage Checkout Building. The nozzle extensions are loaded on low-bed trailers, using a mobile hoist, and towed from the barge to the nozzle extension storage area.

1-208. STAGE FLOW AT MAF. (See figure 1-66.)

1-209. The stage is positioned in the Stage Checkout Building at MAF, and workstands and platforms are installed to aid access during inspection and checkout. The engines undergo a receiving inspection, refurbishment, post-static checkout, and pre-shipment inspection. A storage period may be required after refurbishment, if so, the stage is prepared for storage and stored for a specified time before post-static checkout.

1-210. ENGINE RECEIVING INSPECTION.

1-211. After positioning the stage in the Stage Checkout Building, the engines undergo an overall visual receiving inspection. Each engine is inspected for damage, corrosion, and missing equipment and for evidence of fluid in drain line exits. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas and that there are no voids in the turbopump housing cavity filler material. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. Engine orifice sizes and serialized components are checked against those listed in the Engine Log Book. It is verified that the humidity in the thrust chamber throat security closure indicates blue. Detailed inspection requirements for installed engines received at MAF are in R-3896-11.

1-212. ENGINE REFURBISHMENT.

1-213. The engine is refurbished after receiving inspection. The engines are first cleaned of any foreign matter and corrosion that may have resulted from exposure to rain, humidity, sand, or dust. The oxidizer dome insulator is installed in accordance with requirements specified in R-3896-6. The flight igniter harness is installed, tested, and connected in accordance with requirements specified in R-3896-11. Outstanding maintenance or modification, as required by ECPs and EFIRs, is done during the refurbishment period.

1-214. STAGE STORAGE.

1-215. Storage of installed engines is scheduled following completion of refurbishment. The amount of time the stage remains in storage is determined by the Saturn V vehicle launch schedule. Stage storage, in excess of six months, requires that engine post-static checkout be performed when the stage is removed from storage. Installed engines are visually inspected for damage, corrosion, and missing equipment, and for evidence of fluid in oxidizer and nitrogen purge overboard drain lines. It is also verified that corrosion preventive and aluminum-foil tape is present in specified areas, the gimbal boot is installed, there are no voids in the turbopump housing cavity filler material, and that fuel overboard drain system isolation polyethylene

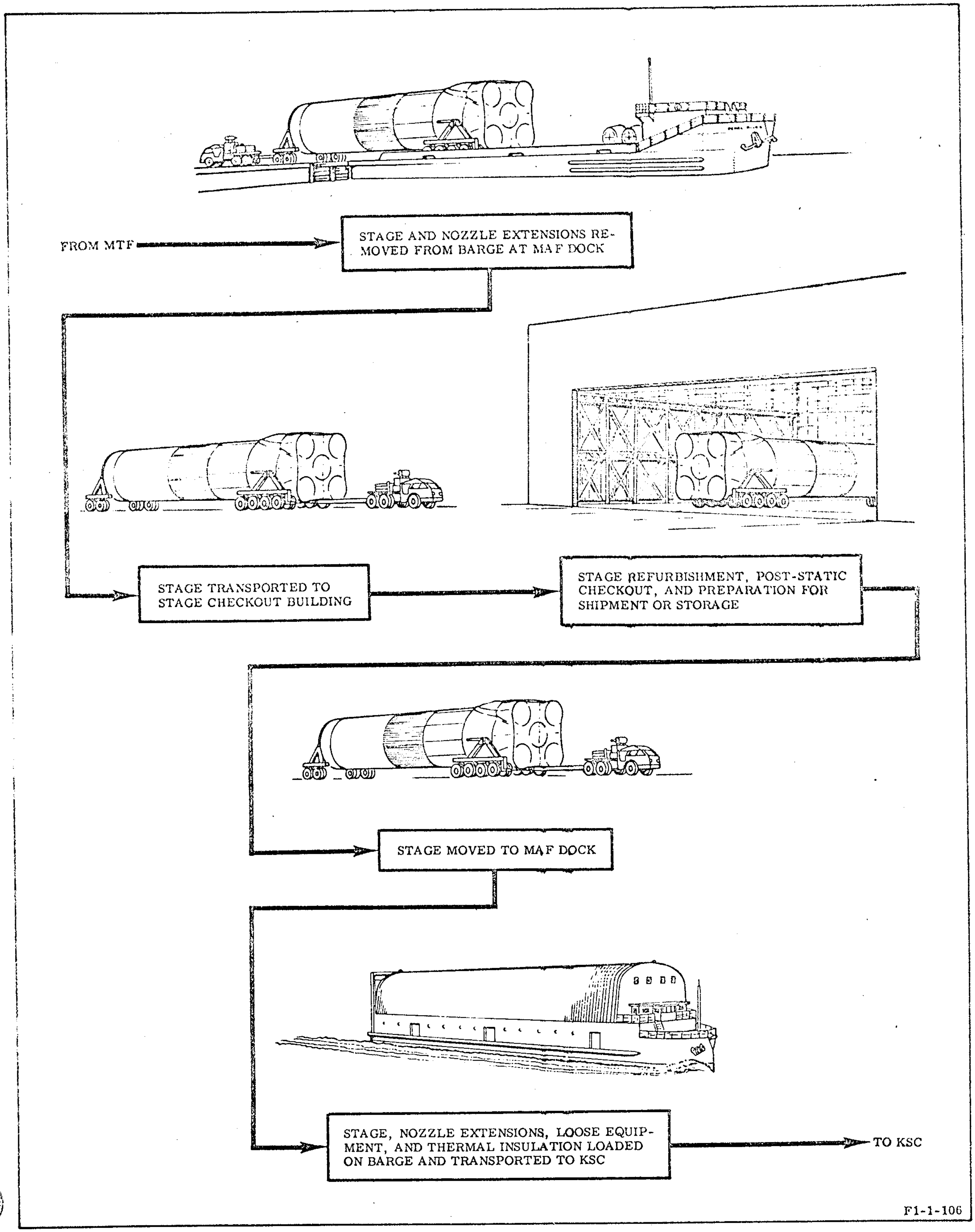


Figure 1-66. Stage Flow at MAF

bags do not contain fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. The turbopump preservation status is checked in the Engine Log Book and the turbopump is serviced if required; desiccants are installed in the thrust chamber throat security closure and the closure is installed; and humidity indicators are checked for a blue indication. The engine-to-stage gimbal actuators are locked to prevent engine movement, and the stage is stored in an environmentally controlled area. The engines are inspected periodically during storage. Detailed inspection requirements for installed engines in storage are in R-3896-11.

1-216. POST-STATIC CHECKOUT.

1-217. The post-static checkout is done after refurbishment tasks are completed, after a stage is removed from storage on which a post-static checkout had not been previously accomplished, or after stage storage has exceeded six months. The post-static checkout consists of complete electrical, hydraulic, and pneumatic leak and functional tests of the installed engines and stage systems. The post-static checkout is completed with a simulated launch test that consists of stage preparations, engine start, ignition, mainstage, liftoff, flight, and engine cutoff in the prescribed sequence to assure flight readiness of the engines and stage. Post-static checkout includes a flight instrumentation function test, turbopump torque test and heater function test, leak and function test of the bearing coolant control valve, hypergol manifold, thrust OK pressure switches, thrust chamber prefill line, ignition monitor valve, oxidizer dome and gas generator oxidizer injector purge system, oxidizer pump seal purge system, cocoon purge system, and hydraulic system. Leak test of the thrust chamber, heat exchanger helium and oxidizer systems, propellant fuel and oxidizer systems, exhaust system, and valve timing function tests are also accomplished. Engine start and cutoff flow sequences are in figures 1-57 and 1-58. Installed engine tests are conducted in accordance with requirements specified in R-3896-11.

1-218. INSTALLED-ENGINE INSPECTION BEFORE STAGE SHIPMENT TO KSC.

1-219. The installed engine is inspected before shipment to KSC and the Engine Log Book is reviewed after post-static checkout tasks are completed. Each engine is visually inspected for damage, corrosion, and missing equipment; for evidence of fluid in drain line exits, fluid on the engine exterior; and for surface wetting on the hydraulic control system exterior. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, that line markings are correct, that the humidity indicator in the thrust chamber throat security closure indicates blue, and that turbopump housing cavity filler material does not contain voids. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. The turbopump preservation status is checked in the Engine Log Book, and the turbopump is serviced if required. A final updating of the Engine Log Book is made before engine shipment to KSC. Detailed procedures for inspecting the installed before shipment to KSC are in R-3896-11.

1-220. <u>STAGE SHIPMENT TO KSC.</u>

1-221. After the engine pre-shipment visual inspection is completed, the forward and aft stage covers are installed, workstands and platforms removed, and the stage pulled from the Stage Checkout Building to the MAF dock for transport to KSC by barge. The nozzle extensions, engine loose equipment, and thermal insulation are loaded on low-bed trailers and transported to the MAF dock where they are removed from the trailers and loaded on the barge and secured for shipment. Handling requirements for nozzle extensions and loose equipment are in R-3896-9. After the nozzle extensions, loose equipment, and thermal insulation boxes are loaded and secured, the stage is loaded onto the barge and secured. The barge is then moved to KSC by tug.

1-222. <u>STAGE FLOW AT KSC</u>. (See figure 1-67.)

1-223. The barge arrives at the KSC dock where the stage, nozzle extensions, loose equipment, and thermal insulation boxes are off-loaded. The stage is towed from the dock to the Vertical Assembly Building (VAB). The nozzle extensions, loose equipment, and thermal insulation boxes are loaded on low-bed trailers and transported to the VAB. The stage is removed from the stage transporter and erected onto the Launch Umbilical Tower (LUT) where the engine visual receiving inspection, loose equipment installation, modification and maintenance, stage and engine leak and functional tests, and thermal

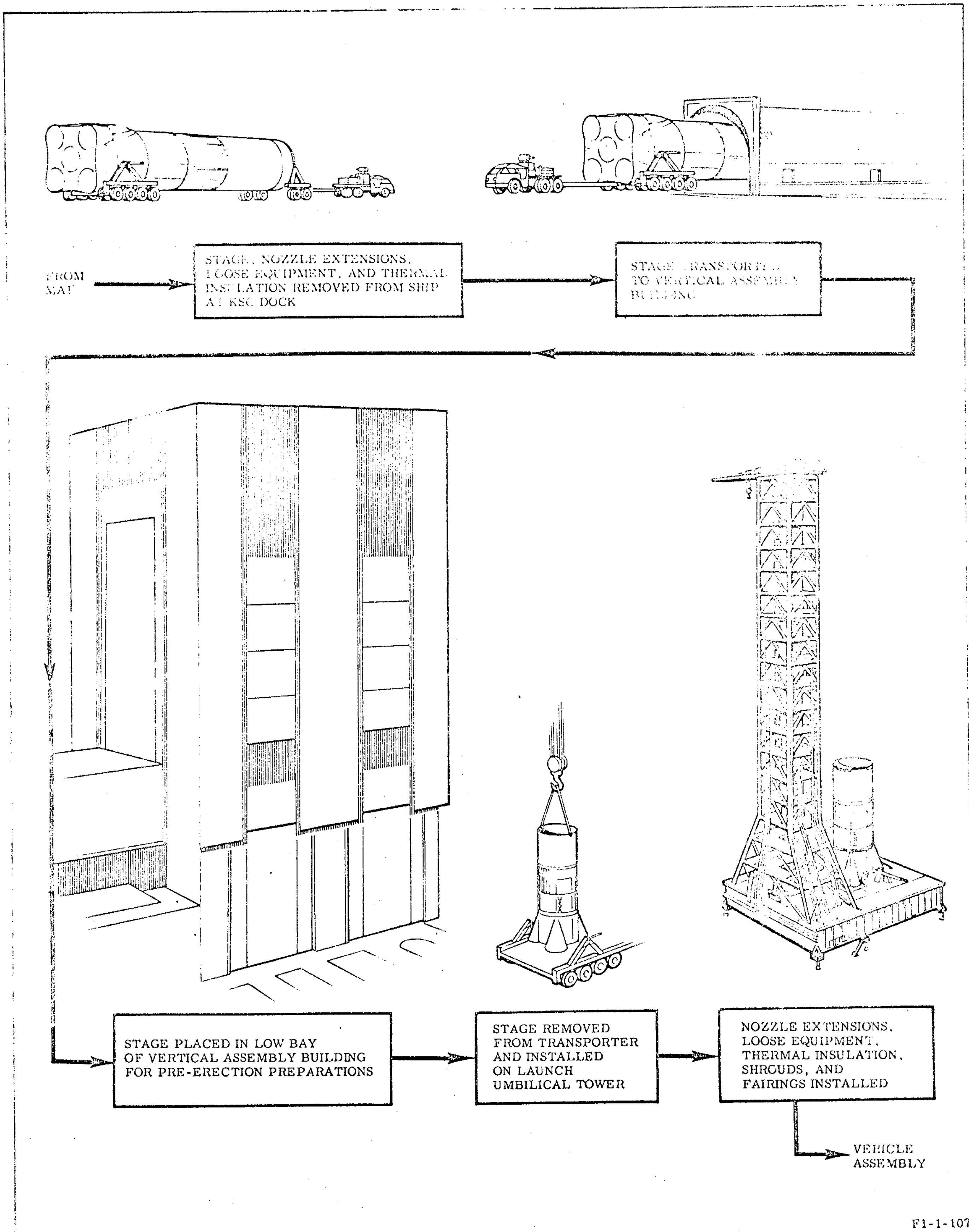


Figure 1-67. Stage Flow at KSC

insulation installations are accomplished. These tasks are conducted concurrently with the Saturn V vehicle assembly and testing. A final updating of the Engine Log Book is made after engine activities during stage flow are complete.

1-224. STAGE INSTALLATION ONTO LAUNCH UMBILICAL TOWER (LUT).

1-225. The stage is received in the low bay of the VAB. The forward and aft stage covers are removed and the stage and engines prepared for rotation and installation onto the LUT. The Engine Service Platform (ESP) and the LUT are moved into the high bay. The stage, on the transporter, is moved from the transfer aisle to the erection bay where the stage is removed from the transporter and rotated to the vertical position by overhead cranes. The stage is then moved by high bay crane and erected on the LUT and secured with four mechanical holddowns. The ESP and LUT level platforms are positioned around the engines for receiving inspection.

1-226. ENGINE RECEIVING INSPECTION.

1-227. After the stage is installed onto the LUT, protective closures are removed and the engines undergo an overall visual receiving inspection. The engines are inspected to verify that damage did not occur during shipping and that all equipment listed on shipping documentation was received. Each engine is inspected for damage, corrosion, and missing equipment; for evidence of fluid in drain line exits, fluid on the engine exterior, and for surface wetting on the hydraulic control system exterior. It is verified that corrosion preventive and aluminum-foil tape is present in specified areas, the engine soft goods installed life is within specified limits, there are no voids in the turbopump housing cavity filler material, and that turbopump and outrigger arm surfaces do not contain scratches through paint. The fuel overboard drain system isolation polyethylene bags are visually inspected for fluid. If fluid is present, the bags are emptied and the quantity of fluid is measured. Engine orifice sizes and serialized components are checked against those listed in the Engine Log Book. Oxidizer and fuel high-pressure duct covers and thrust chamber covers are installed after visual inspection completion. Detailed inspection requirements for installed engines received at KSC are in R-3896-11.

1-228. LOOSE EQUIPMENT INSTALLATION.

1-229. The engine loose equipment is installed after engine receiving inspection is completed. The loose equipment consists of the nozzle extension, oxidizer overboard drain line, fuel overboard drain line, nitrogen purge overboard drain line, and fuel inlet elbow-to-interface boots. Using Engine Handler Sling G4052 and overhead cranes, the nozzle extension is removed from Nozzle Extension Handling Fixture G4080 and Handling Adapter G4081 and placed on the Nozzle Extension Installer. The five nozzle extensions and Nozzle Extension Installers are placed on the Engine Service Platform in their respective engine positions. The Engine Service Platform is then raised from ground level up through the opening in the LUT until the nozzle extension flanges are approximately 5 inches below the thrust chamber exit flanges. Final adjustments are made and the mating of the extension flanges to the thrust chamber exit flanges is done with the individual Nozzle Extension Installers. After the nozzle extensions are secured to the engines, the overboard drain lines are attached and secured. Loose equipment is installed in accordance with requirements specified in R-3896-11. Detailed nozzle extension handling requirements are in R-3896-9. The stage fins and engine shrouds are installed in accordance with stage contractor requirements.

1-230. MODIFICATION AND MAINTENANCE.

1-231. The engine modifications and special inspections may be made and maintenance tasks may be performed, if required, throughout the stage flow at KSC. Modifications and special inspections are made as a result of approved ECP or EFIR action, and scheduled through joint agreement between the customer, stage contractor, and engine contractor. The engine maintenance is performed, if required, as a result of discrepant hardware noted during receiving inspection or engine leak and functional testing.

1-232. STAGE FUNCTIONAL TEST.

1-233. The stage functional testing is started after stage installation onto the LUT. The electrical, hydraulic, and pneumatic leak and functional tests are made in conjunction with vehicle assembly. The stage functional test consists of a flight instrumentation function test, turbopump torque test and heater function test, engine sequence verification test, leak and function test of the bearing coolant system, hypergol manifold, thrust OK pressure switches, thrust chamber prefill line, ignition monitor valve, oxidizer dome and gas generator oxidizer injector purge system, oxidizer pump seal purge system, cocoon purge system, and hydraulic system. A leak test of the thrust chamber, heat exchanger helium and oxidizer systems, propellant fuel and oxidizer systems, exhaust system, and valve timing function tests is also performed. Installed engine tests are performed in accordance with requirements specified in R-3896-11.

1-234. THERMAL INSULATION INSTALLATION.

1-235. The thermal insulation (TIS) is installed after engine leak and functional testing is complete. The TIS is installed to completely envelop the engine and provide protection from extreme temperatures created by plume radiation and backflow during cluster engine flight. To allow access for verifying the integrity of engine components and systems and to prevent possible insulator damage from fluid spillage, the TIS is not installed until engine testing is complete. The required sequence and methods for TIS installation is in R-3896-6. After the thermal insulation is installed and before moving the Saturn V vehicle from the VAB, an engine environmental cover is installed on each S-IC engine, from the thrust chamber throat area to the exit end of the nozzle extension, to protect the thermal insulation from inclement weather. The cover is wrapped around the thrust chamber and nozzle extension and placed so that engine overboard drain lines are exposed through holes provided in the cover, and access flaps, four places, are located to provide access to drain ports and igniters. Overlapping edges of the cover are laced together, excess material is gathered around the thrust chamber throat and folds tied, and the cover drawn tight under exit end of nozzle extension. Detailed requirements for installation of the cover are in R-3896-11.

1-236. SATURN V VEHICLE FLOW AT KSC. (See figure 1-68.)

1-237. While the S-IC Stage is being received and erected in the VAB, the S-II Stage, S-IVB Stage, and Instrumentation Unit are received in the VAB and placed in the checkout bays where they undergo a complete pre-erection checkout. Upon completion of S-IC Stage erection, the Saturn V Vehicle assembly is started, concurrently with S-IC Stage testing. When the fins, fairings, engine shrouds, and nozzle extensions are installed, the S-IC Stage assembly is complete. The Instrumentation Unit is moved into the high bay, placed on a platform near the S-IC Stage, and an S-IC Stage-Instrumentation Unit-checkout is performed. Upon completion of pre-erection checkout, the S-II Stage is moved from the checkout bay to the high bay and mated with the S-IC Stage. The S-IVB Stage is moved from the checkout bay and mated with the S-II Stage, and the Instrumentation Unit is removed from the platform and mated with the S-IVB Stage, completing the assembly of the Launch Vehicle (LV). After individual modules are checked out at the Manned Spacecraft Operations Building (MSOB), the Apollo spacecraft, consisting of the mated lunar excursion, and service and command modules, is moved into the VAB and mated mechanically (lunar excursion module-adapter to forward mating flange of instrumentation unit).

1-238. VEHICLE TESTING.

1-239. After the Apollo spacecraft and launch vehicle are mechanically mated, spacecraft modules are connected to their umbilicals from the umbilical tower of the mobile launcher and pre-power-on tests are made. When it has been determined that all flight and ground systems are satisfactory, full power is applied to the spacecraft. The spacecraft is then mated electrically to the launch vehicle and combined system tests, consisting of simulated countdowns and flights that exercise both flight and ground systems, are made. During the final combined system testing phase, the spacecraft and launch vehicle ordnance, minus pyrotechnics, are installed including the launch escape system. When the combined system testing is complete, the test data is reviewed, and if acceptable, the Saturn V vehicle is ready to be moved to the launch pad.

1-240. TRANSFERRING VEHICLE TO LAUNCH PAD.

1-241. The Apollo/Saturn V is transported from the VAB to the launch pad by the crawler transporter. The extendible platforms that enclosed the vehicle in the VAB are retracted, connections between the mobile launcher terminals and the terminals in the high bay are disconnected, the doors of the high bay are opened, and the transporter brought in and

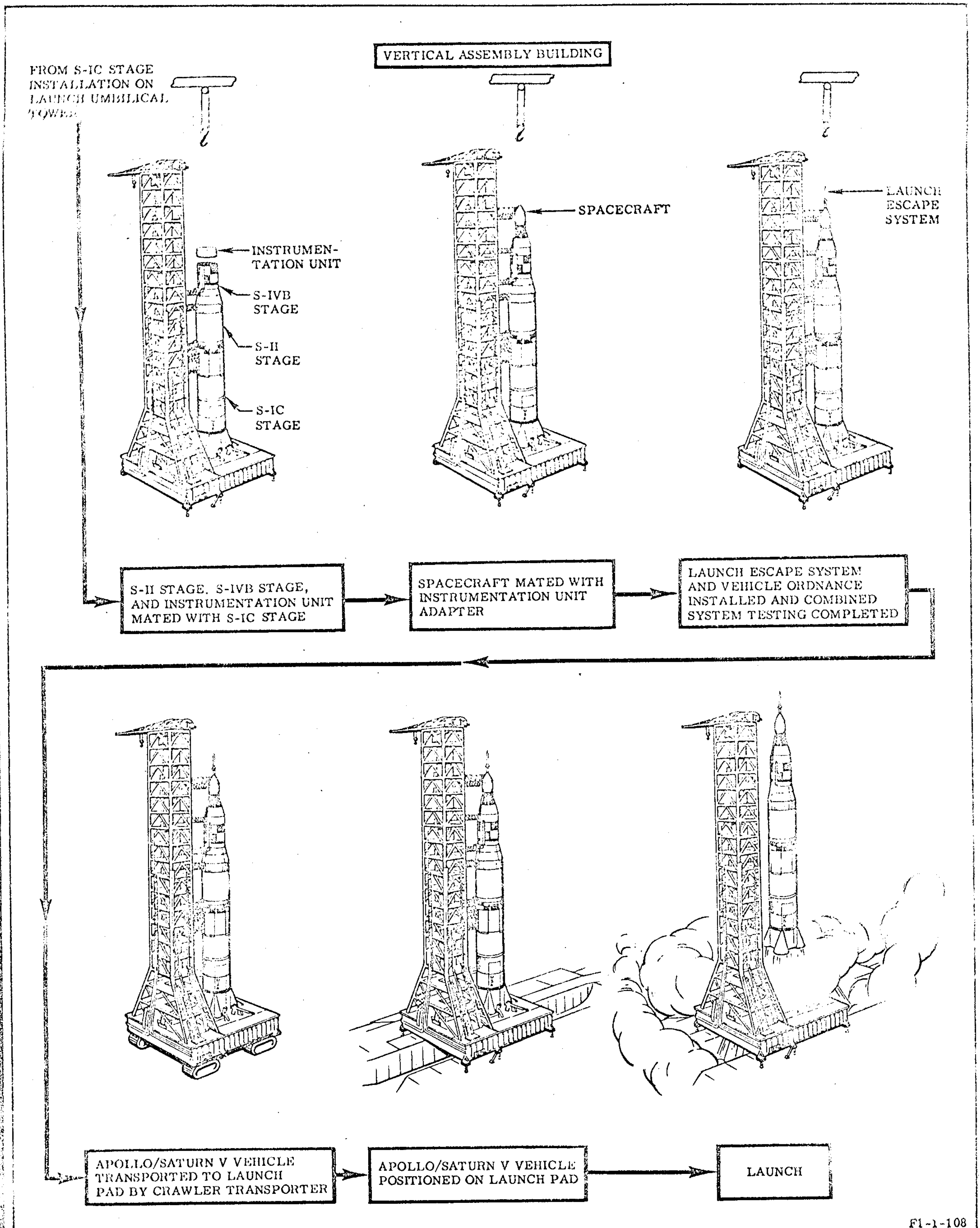


Figure 1-68. Saturn V Vehicle Flow at KSC

positioned beneath the platform section of the launcher. Hydraulic jacks are extended from the transporter to lift the launcher clear of its pedestals. Then, at a speed of approximately 1 mph, the transporter carries the launcher and the fully assembled Apollo/Saturn V to the launch pad for positioning.

1-242. LAUNCH PREPARATIONS AND TESTING.

1-243. After all electrical and pneumatic lines to the Apollo/Saturn V are reconnected through terminals at the base of the mobile launcher, and propellant lines, also connected through the launcher, are verified as correct, and it has been ascertained that no changes have occurred in the vehicle since it left the VAB, tests are made on the communication links to the vehicle. Measurements are also taken on systems such as the cutoff abort unit, radio-frequency, tank pressurization, and launch vehicle stage propellant utilization system. A Flight Readiness Test (FRT), backup guidance system test, and S-IC fuel jacket/oxidizer dome flush and purge are performed. Hypergolic propellants are loaded in the spacecraft tanks, RP-1 fuel is loaded in the launch vehicle tanks, and Countdown Demonstration Tests (CDDT) are performed. Liquid oxygen and liquid hydrogen are loaded into the launch vehicle during the last few hours of the countdown.

1-244. SATURN V VEHICLE LAUNCH.

1-245. The data in this paragraph is only used to describe a typical vehicle launch and is not intended to represent actual launch data. With S-IC stage engines and launch vehicle preparations complete, the S-IC engines are fired, all holddown arms are released, and the vehicle committed for liftoff. The vehicle rises nearly vertically from the launch pad, for approximately 450 feet, to clear the launch umbilical tower. During liftoff, a yaw maneuver is executed to provide tower clearance in the event of adverse wind conditions or deviations from nominal flight. After clearing the tower, a tilt and roll maneuver is initiated to achieve the flight attitude and proper orientation from the selected flight azimuth. The S-IC center engine cutoff occurs at 2 minutes 5.6 seconds after first vehicle motion to limit the vehicle acceleration to a nominal 3.98 G-load. The S-IC outboard engines are cutoff at 2 minutes 31 seconds after first vehicle motion. Following S-IC engines cutoff, ullage rockets are fired to seat S-II stage propellants, the S-IC/S-II stages separate, and retrorockets back the S-IC stage away from the flight vehicle. A time interval of 4.4 seconds elapses between S-IC engines cutoff and the time the S-II engines reach 90 percent operating thrust level. Following the programmed burn of S-II engines, the S-II/S-IVB stages separate and the S-IVB engine places the flight vehicle in an earth parking orbit.

1-246. POST-FLIGHT DATA EVALUATION.

1-247. The post-flight data is evaluated to determine that the S-IC stage engines operated within the specified values during vehicle launch. The engine parameters are reviewed for abnormalities, sudden shifts, oscillations, or performance near the minimum or maximum limits. The engine performance values are then reviewed and compared to the predicted engine values to determine that all engine objectives were satisfactorily met.

1-248. UNSCHEDULED MAINTENANCE FLOW.

1-249. Unscheduled maintenance consists of those operations required in addition to normal engine and hardware processing, to repair damage, replace discrepant components or hardware, perform modifications and EFIRs, decontaminate, re-preserve, repair thermal insulation, or rectify any unsatisfactory condition. The unscheduled maintenance tasks are done at a specified time and at the location designated, during the normal engine flow process. The locations where unscheduled maintenance can be done are Rocketdyne, MAF, MTF, or KSC; depending on the extent of the task, urgency, capabilities of the location, and how schedules are affected. The location established for complete component maintenance, repair, and testing is the CM&R room at MAF. This facility provides component maintenance support for MAF, MTF, and KSC. Limited repairs on components can be made in-place on the engine at MAF, MTF, or KSC as directed by the customer. The necessary hardware required for supporting engine and component repairs at field locations is stored and maintained at MAF.

1-250. UNSCHEDULED ENGINE REPAIR AND SERVICING.

1-251. Unscheduled engine repair and servicing consists of various types of repairs and servicing tasks that are done whenever practical to correct any discrepancies that may exist, perform special inspections, and to update the engine configuration. The various repairs and servicing tasks may include such items as: braze and weld repair thrust chamber tubes, remove and replace components, clean contaminated areas, remove corrosion, touch-up of damaged surface finishes, modifications, EFIRs, post-maintenance tests, lubricate, preserve, and replace desiccants.

1-252. COMPONENT REPAIR.

1-253. Uninstalled engine components from MAF, MTF, or KSC that require repair, modification, analysis or testing are processed in the environmentally controlled CM&R room at MAF. Processing engine components in the CM&R room is required to repair a discrepant component from an engine, perform modifications, failure analysis, inspections, recycle testing, or pre-installation testing. After processing in the CM&R room, the components are designated to be installed on an engine, returned to the engine support hardware center as a spare, returned to the manufacturer, or considered as surplus or scrap. Detailed procedures for component maintenance and repair are in R-3896-3.

1-254. SUPPORT HARDWARE.

1-255. Engine hardware required for supporting the activities at MAF, MTF, and KSC is maintained in the Engine Support Hardware Center at MAF. The Michoud facility is the primary hardware supply center, since the majority of engine and component activity takes place at this location. At MTF and KSC a limited inventory of hardware is maintained to make sure of immediate availability of those items frequently used at these locations. Whenever an urgent need arises at either MTF or KSC, and the hardware required is not locally available, the item is expedited to that location directly from MAF or Rocketdyne.

SECTION II

INTERFACE DESIGN CRITERIA

2-1. SCOPE. This section contains data pertaining to engine design performance characteristics, environmental conditions, attitude, mass properties data, turbopump inlet propellant conditions, and interface connections for mating the engine with the S-IC of the Saturn V vehicle.

2-2. DESIGN PERFORMANCE CHARACTERISTICS.

2-3. Design performance characteristics describe requirements necessary to achieve specific engine performance. The following ratings, data, and curves are based on standard sea-level static conditions, unless otherwise noted.

2-4. ROCKET ENGINE RATINGS.

2-5. The performance ratings specified in figure 2-1 are values based on the use of fuel at a standard density of 50.45 lb/ft^3 and oxidizer at the standard density of 71.38 lb/ft^3. Refer to section III for fuel and oxidizer density versus temperature curves.

2-6. NOMINAL ALTITUDE PERFORMANCE.

2-7. The nominal altitude performance curves (figure 2-3) depict specific impulse and thrust of the engine as affected by variations in altitude.

2-8. OXIDIZER PUMP CAVITATION.

2-9. The oxidizer pump cavitation curve (figure 2-4) specifies the oxidizer net-positive suction head requirements that must be supplied by the vehicle.

2-10. FUEL PUMP CAVITATION.

2-11. The fuel pump cavitation curve (figure 2-5) specifies fuel net-positive suction head requirements that must be supplied by the vehicle.

2-12. TURBOPUMP INLET PRESSURE REQUIREMENTS.

2-13. The acceptable pre-start turbopump inlet propellant pressures are presented in figure 2-6.

Parameter	Value
Thrust[a]	1,522,000 lb ±1-1/2%
Instantaneous Specific Impulse[b]	263.7 sec min
Oxidizer/Fuel Mixture Ratio[b]	2.27 ±2%
Standard Propellant Pump Inlet Pressures, total	45 psia (fuel) 65 psia (oxidizer)
Effective Duration	165 sec

(a) The engine thrust is that force acting parallel to the engine centerline, including gas generator exhaust thrust, and is corrected to standard propellant densities, pump inlet pressures, and sea-level atmospheric pressure.

(b) The value is based on the total gas generator and thrust chamber flowrates at rated engine thrust and mixture ratio, and is corrected to standard propellant densities, inlet pressures, and sea-level atmospheric pressure.

Figure 2-1. Rocket Engine Ratings at Standard Sea-Level Conditions

Figure 2-2 deleted.

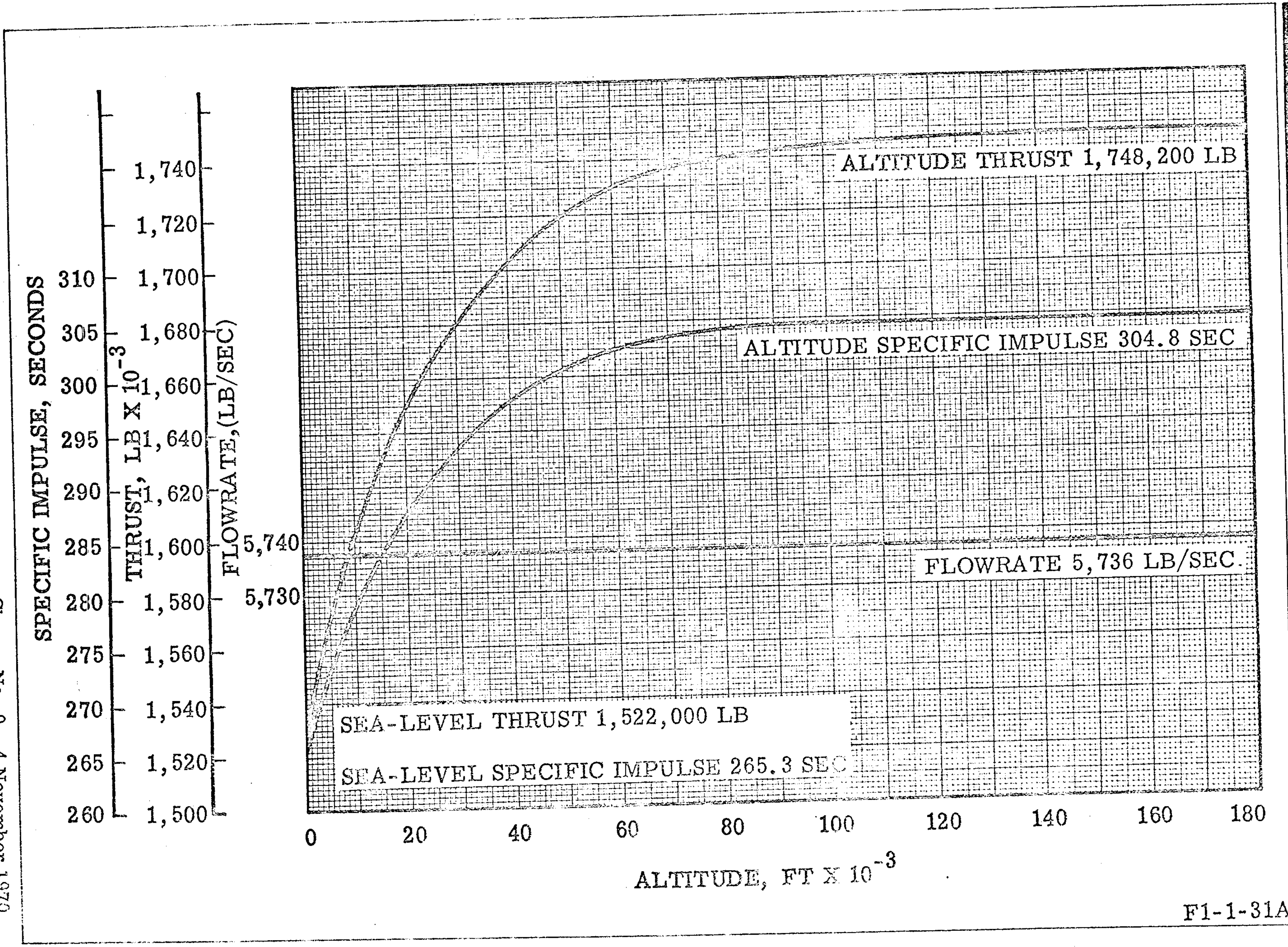


Figure 2-3. Nominal Altitude Performance

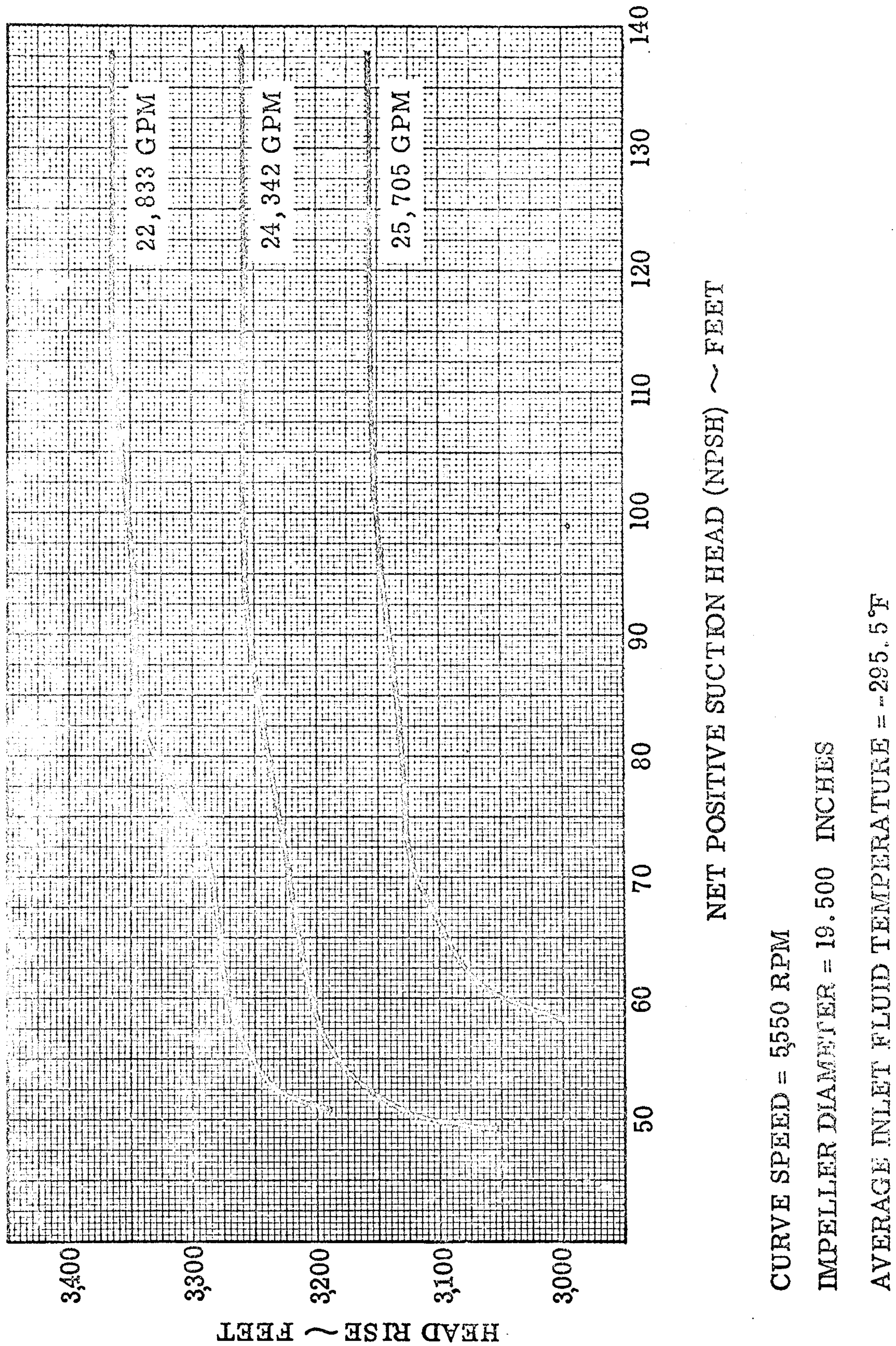
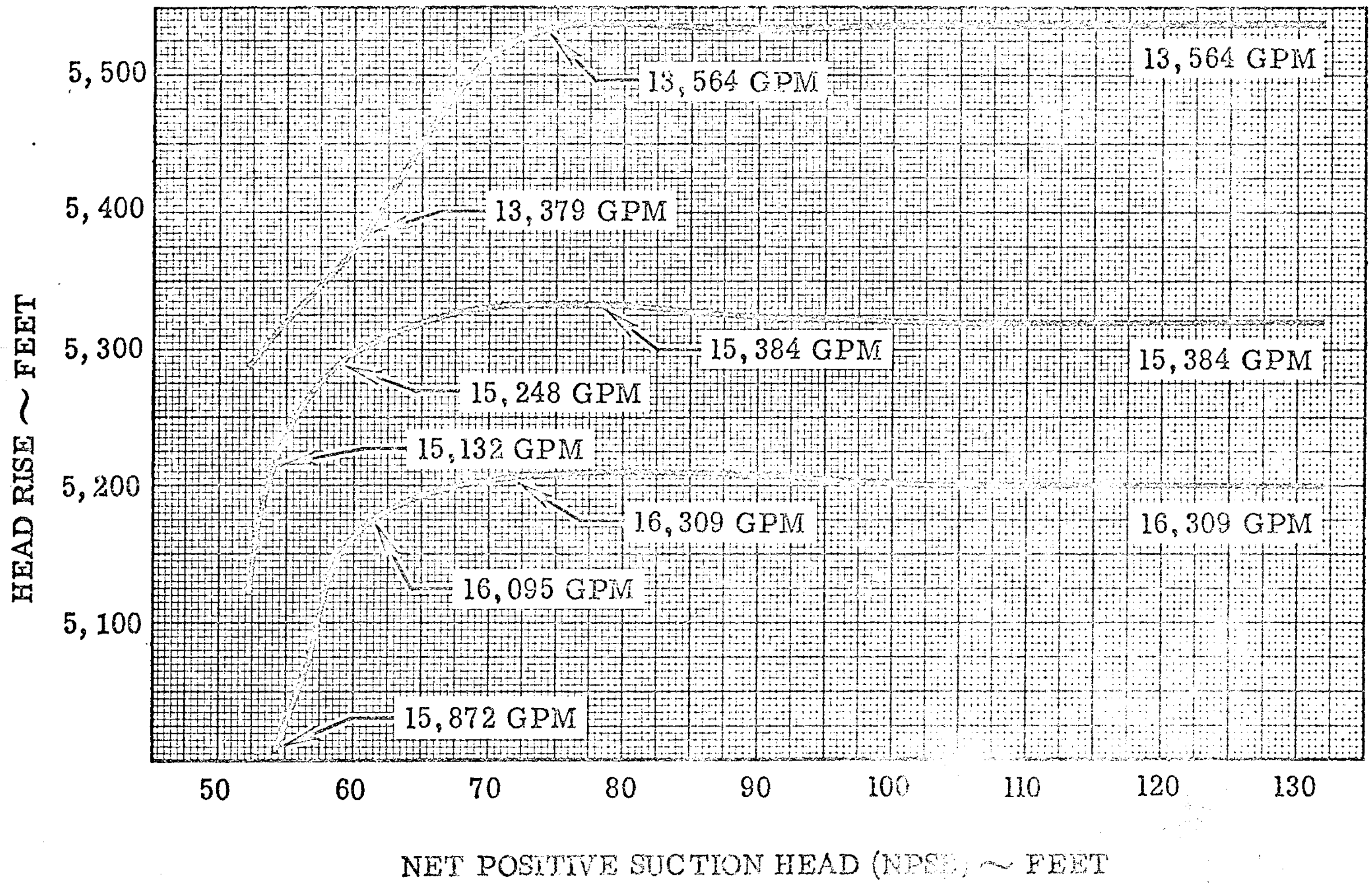


Figure 2-4. Oxidizer Pump Cavitation Characteristics



CURVE SPEED = 5,550 RPM
IMPELLER DIAMETER = 22,850 INCHES
AVERAGE STARTING INLET FLUID TEMPERATURE = 80.0°F

104001-G-11 E

Figure 2-5. Fuel Pump Cavitation Characteristics

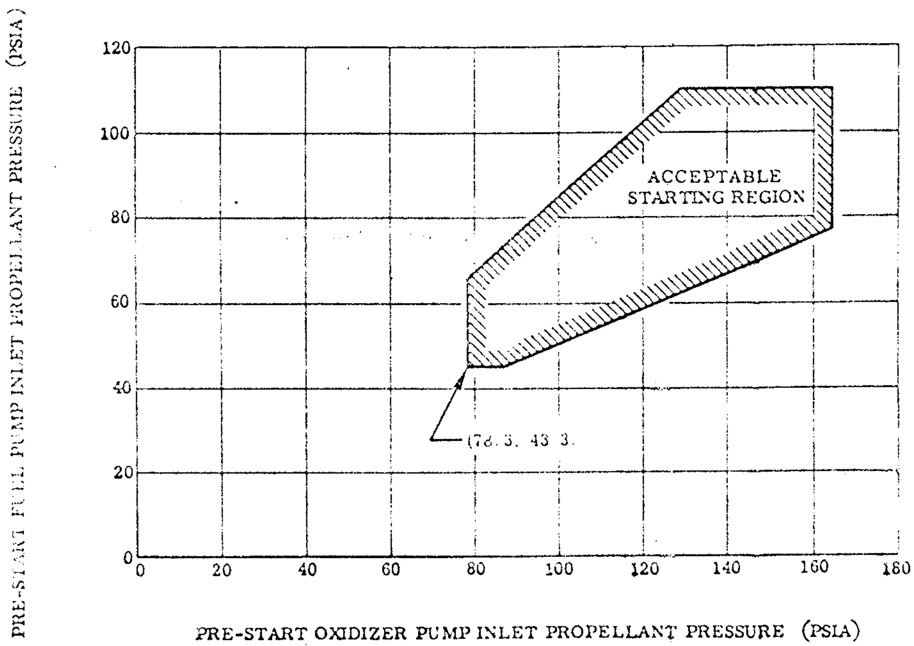


Figure 2-6. Acceptable Pump Inlet Propellant Pressures for Starting Engine

2-14. HEAT EXCHANGER PERFORMANCE.

2-15. See figure 2-7 for heat exchanger flowrate values. See figures 2-8 and 2-9 for helium and oxidizer temperatures versus flow and accumulated engine test duration curves. See figures 2-9A through 2-9M for heat exchanger transient and steady-state performance characteristics at constant turbopump inlet conditions.

2-16. HYDRAULIC CONTROL SYSTEM NOMINAL FLOW AND PRESSURE VALUES.

2-17. See figure 2-10 for hydraulic flowrate at nominal control system values.

2-18. ENVIRONMENTAL CONDITIONS.

2-19. STORAGE AND HANDLING TEMPERATURE.

2-20. The engine will not suffer detrimental effects when exposed to an ambient temperature range of -20° to +130° F at a relative humidity of 95 percent during handling and transportation operations and extended storage periods.

Parameter	Value
Oxygen Flowrate	3.0 to 15.0 lb/sec
Helium Flowrate	0.4 to 1.0 lb/sec

Figure 2-7. Heat Exchanger Flowrates

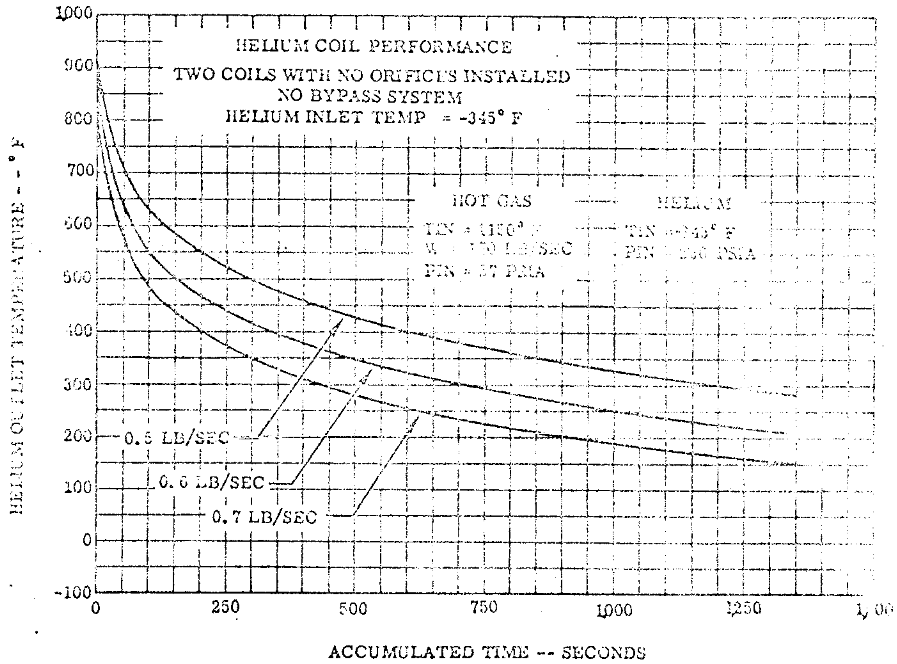
2-21. STORAGE AND HANDLING ATTITUDE.

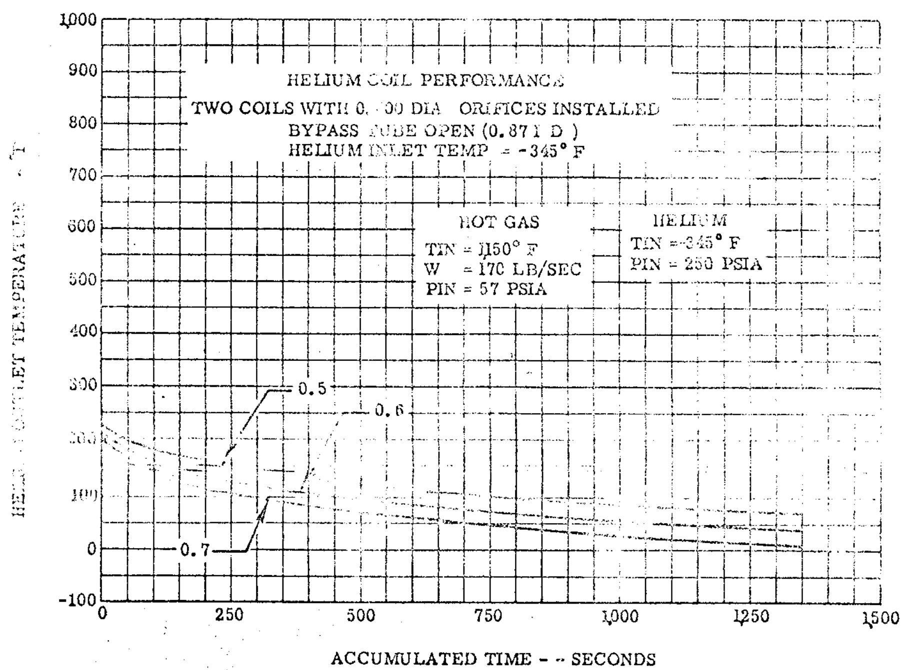
2-22. The engine will not suffer detrimental effects when the engine attitude is maintained at less than 90 degrees from the normal vertical attitude (thrust chamber down) during handling and transportation operations, extended storage periods, and those maintenance tasks outlined in R-3896-3.

2-23. STANDBY EXPOSURE.

2-24. The engine with or without thermal insulation installed, when supplied with required operating fluids, electrical power, and fuel propellant only, will not suffer detrimental effects when exposed to an ambient temperature range of 0° to 130° F for 48 hours, except as limited by the freezing point of the thrust chamber prefill fluid.

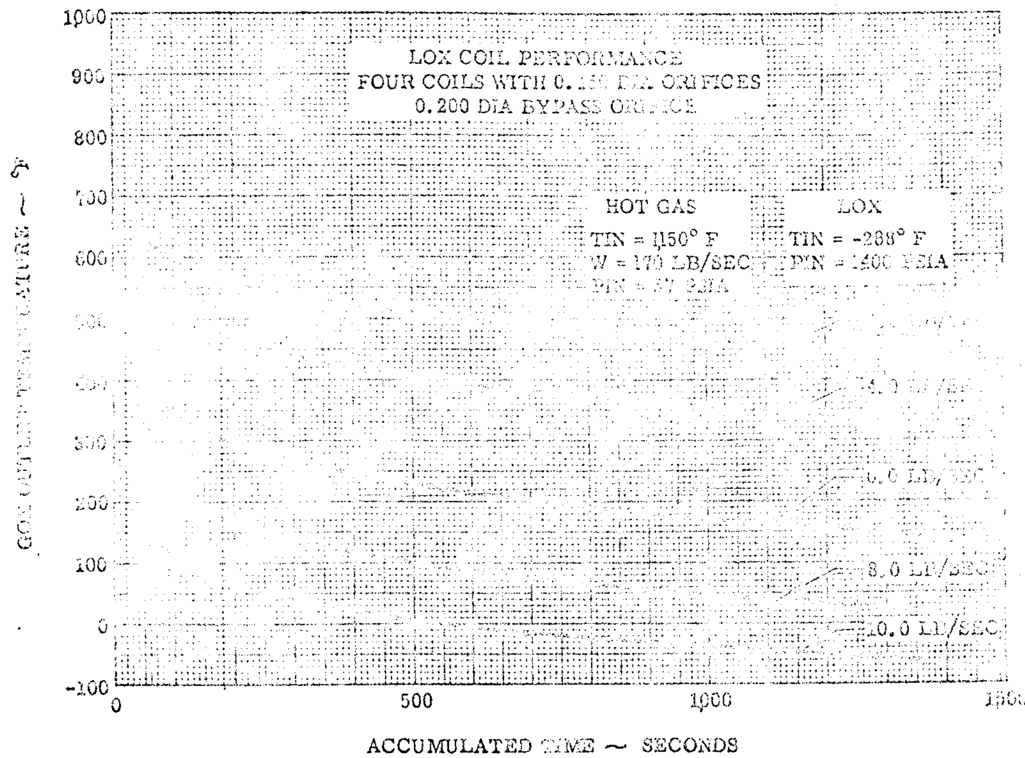
Pages 2-6A and 2-6B deleted.





104001-G-32B

Figure 2-8. Helium Temperature Versus Flow and Accumulated Engine Test Duration Curve



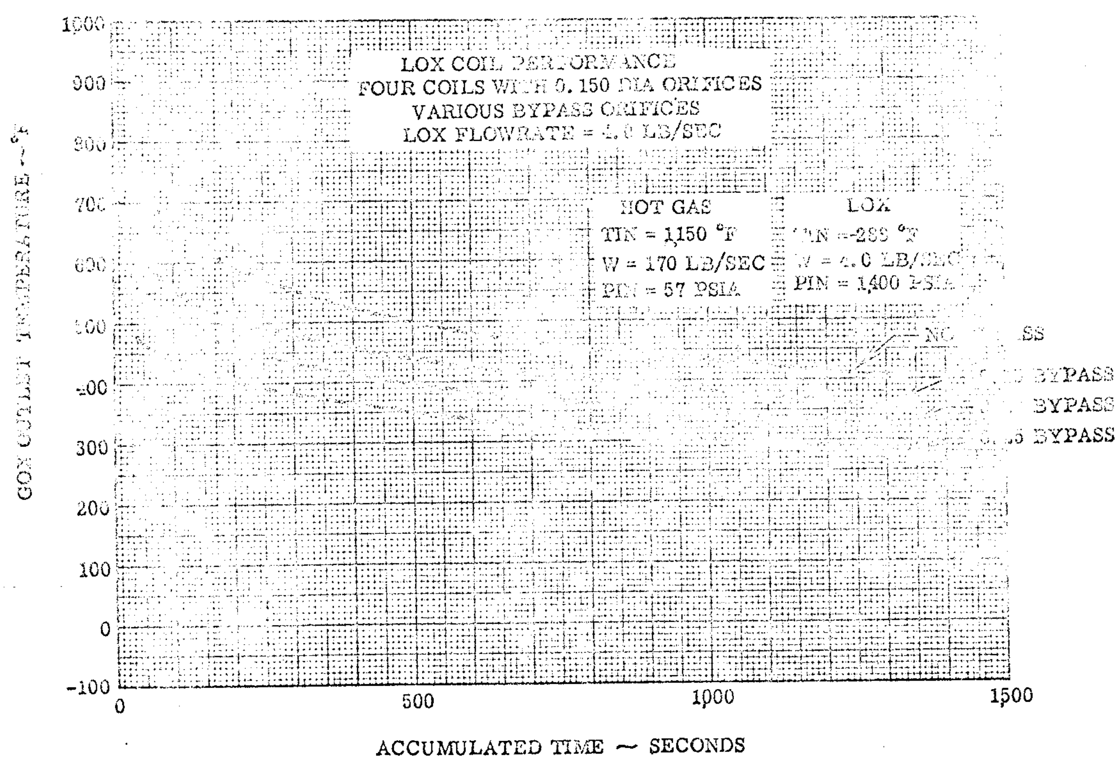


Figure 2-9. LOX Temperature Versus Flow and Accumulated Engine Test Duration Curve

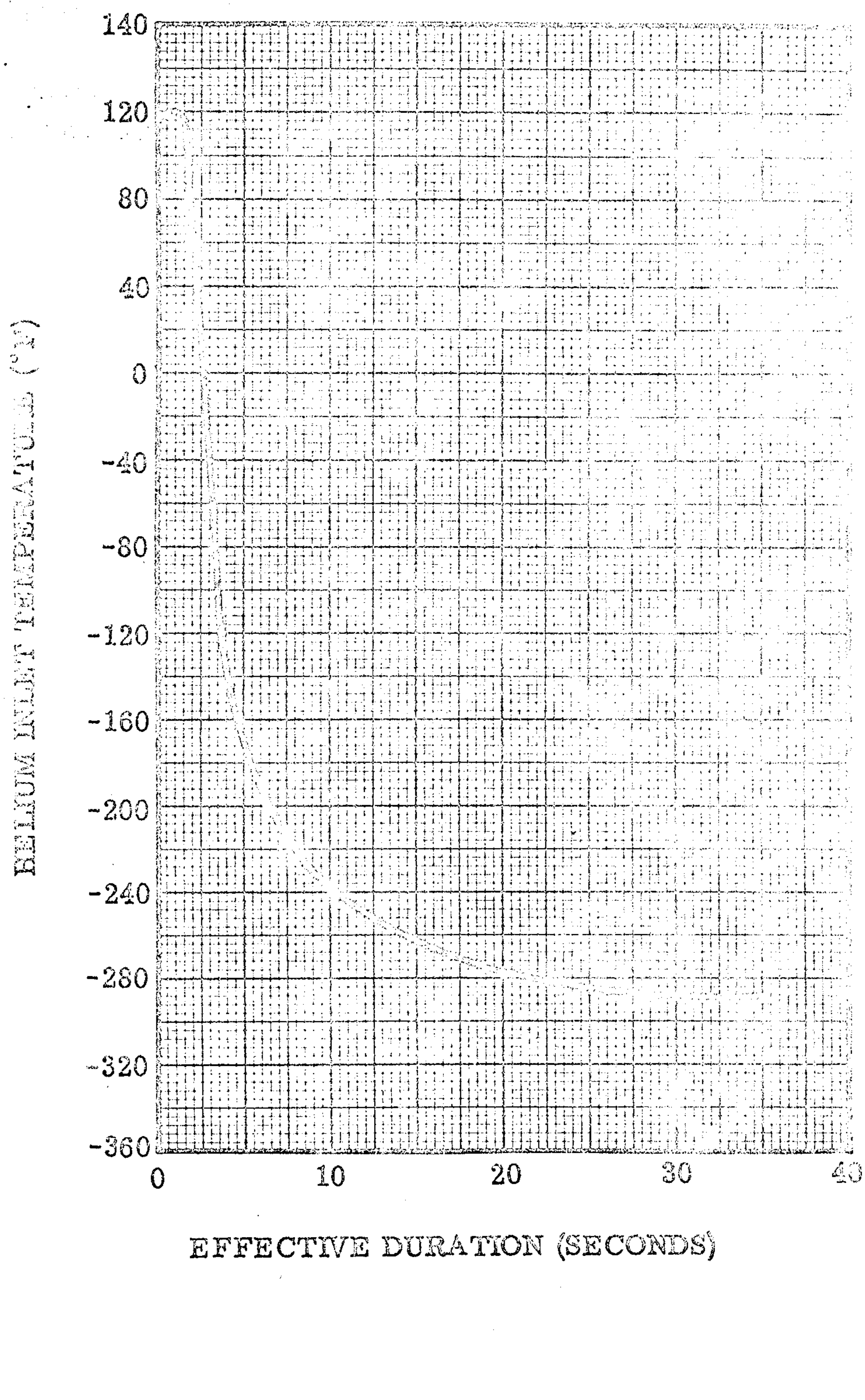


Figure 2-9A. Estimated Helium Inlet Temperature Transient for Heat Exchanger

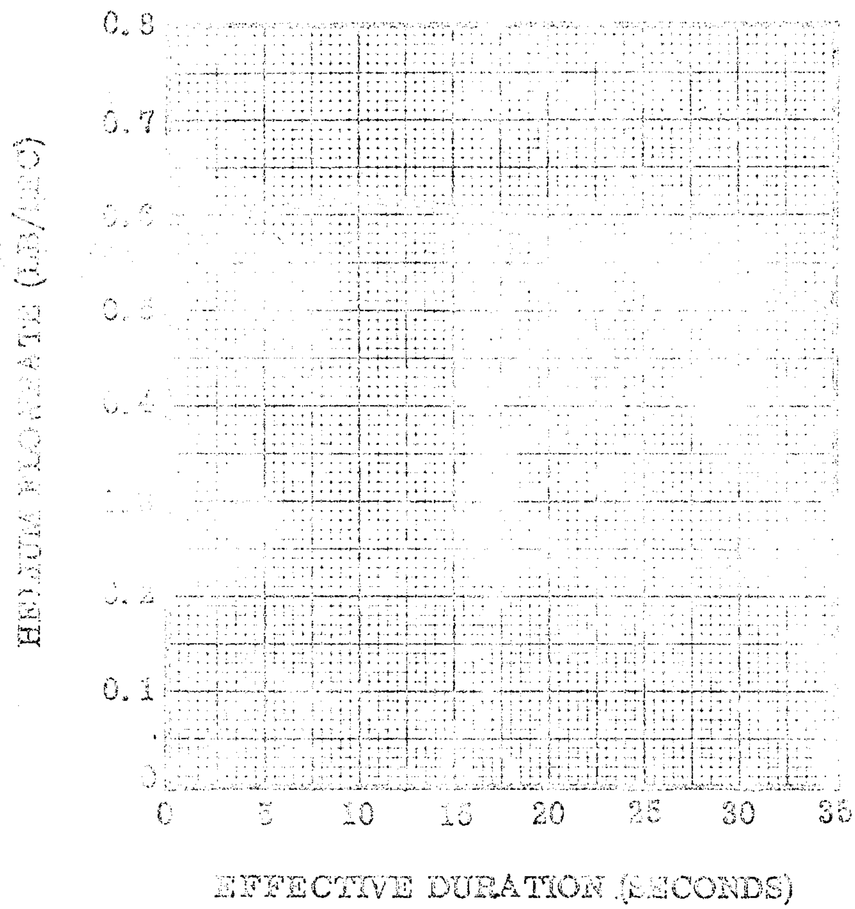


Figure 2-3B. Estimated Helium Flowrate Transient for Heat Exchanger

Figure 2-9C deleted.

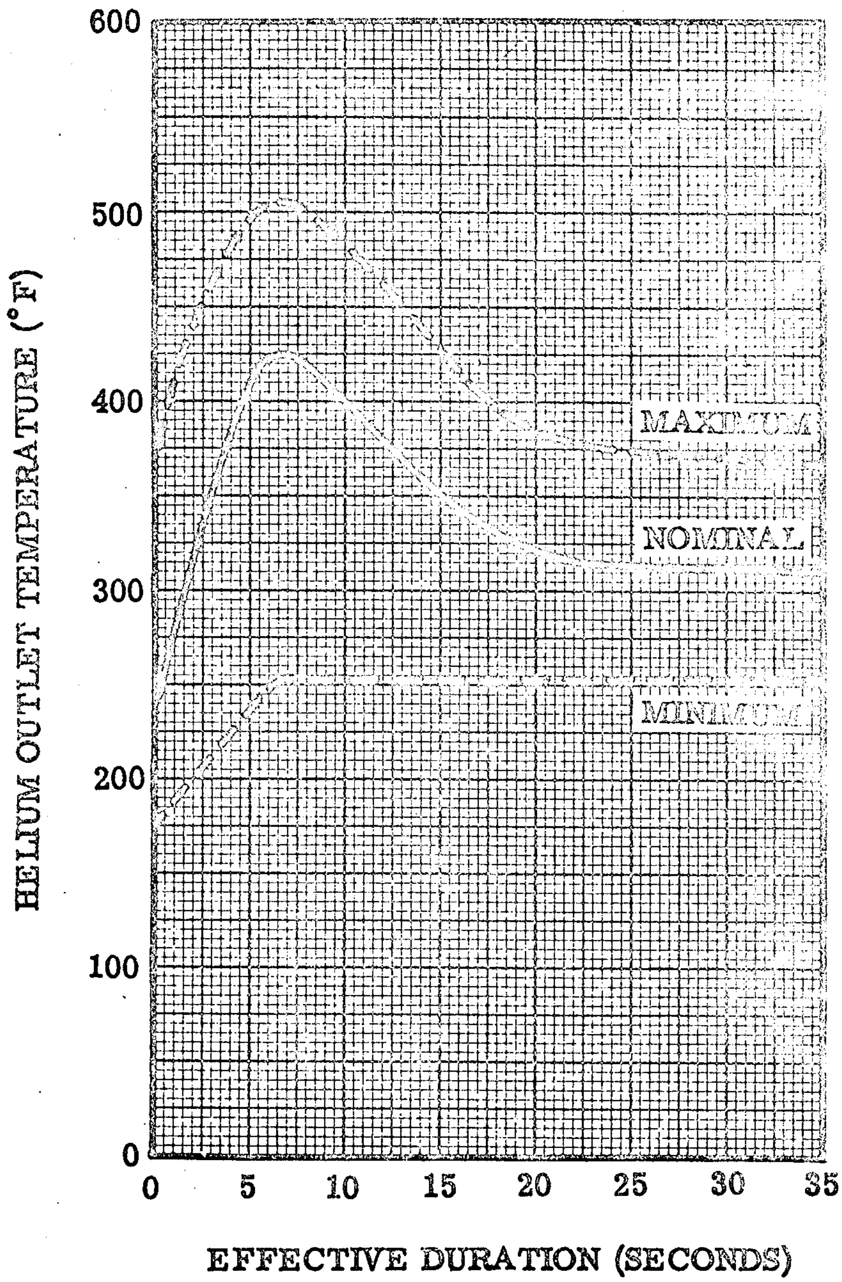


Figure 2-9D. Estimated Helium Outlet Temperature Transient for Heat Exchanger

Figure 2-9E deleted.

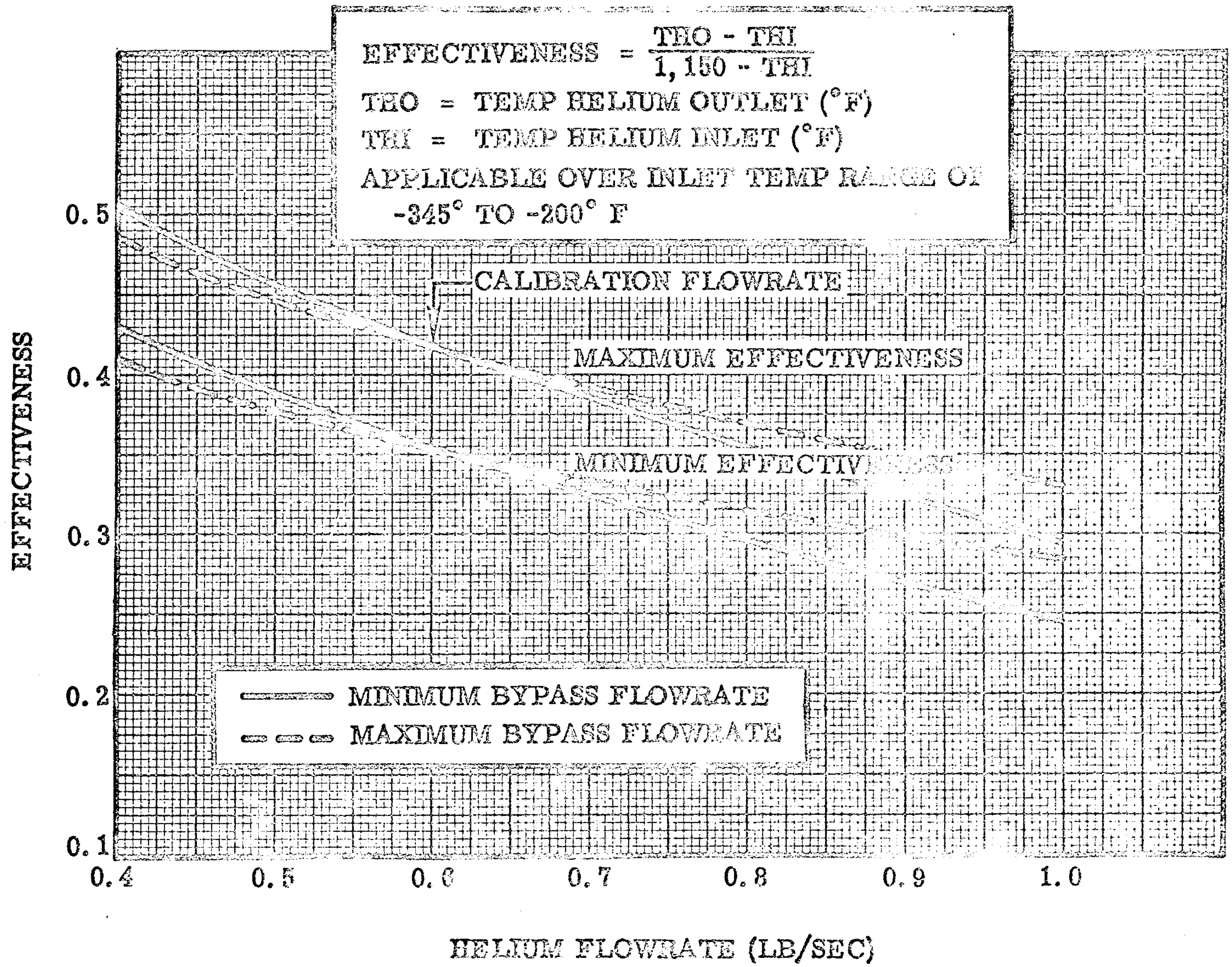


Figure 2-9F. Estimated Helium Effectiveness Versus Helium Flowrate for Steady-State Operation of Heat Exchanger

Pages 2-8G and 2-8H, figure 2-9G deleted.

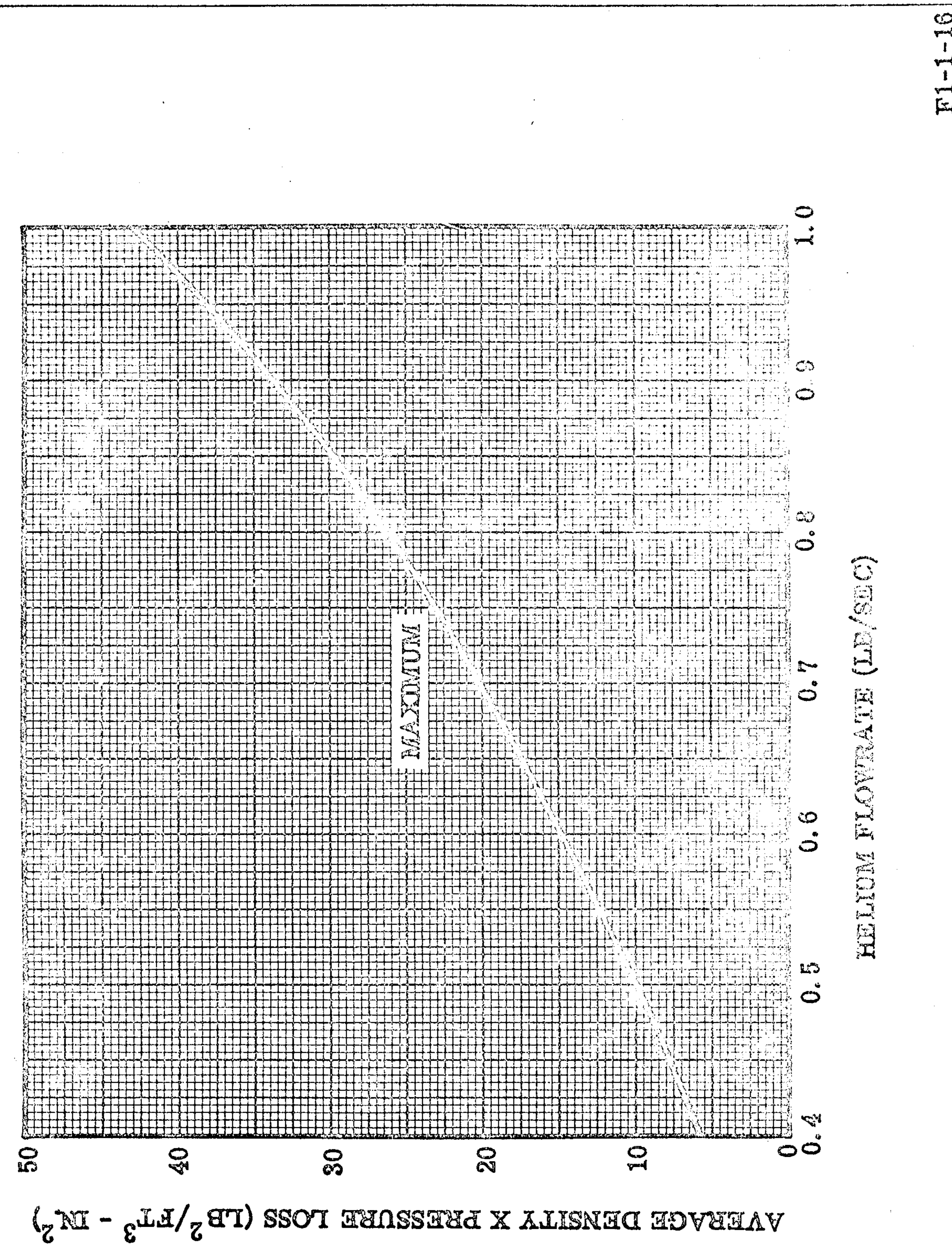


Figure 2-9H. Estimated Helium Pressure Loss Versus Helium Flowrate for Steady-State Operation of Heat Exchanger

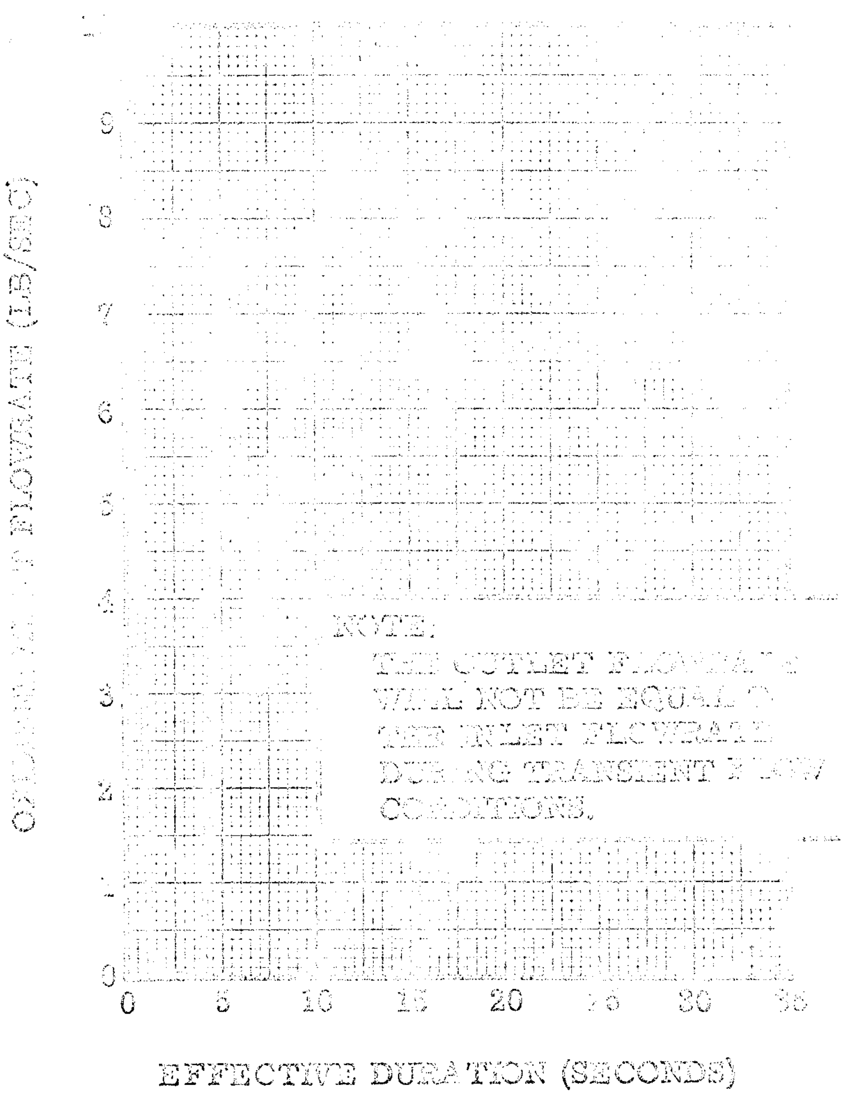


Figure 2-9J. Estimated Oxidizer Flowrate Transient for Heat Exchanger

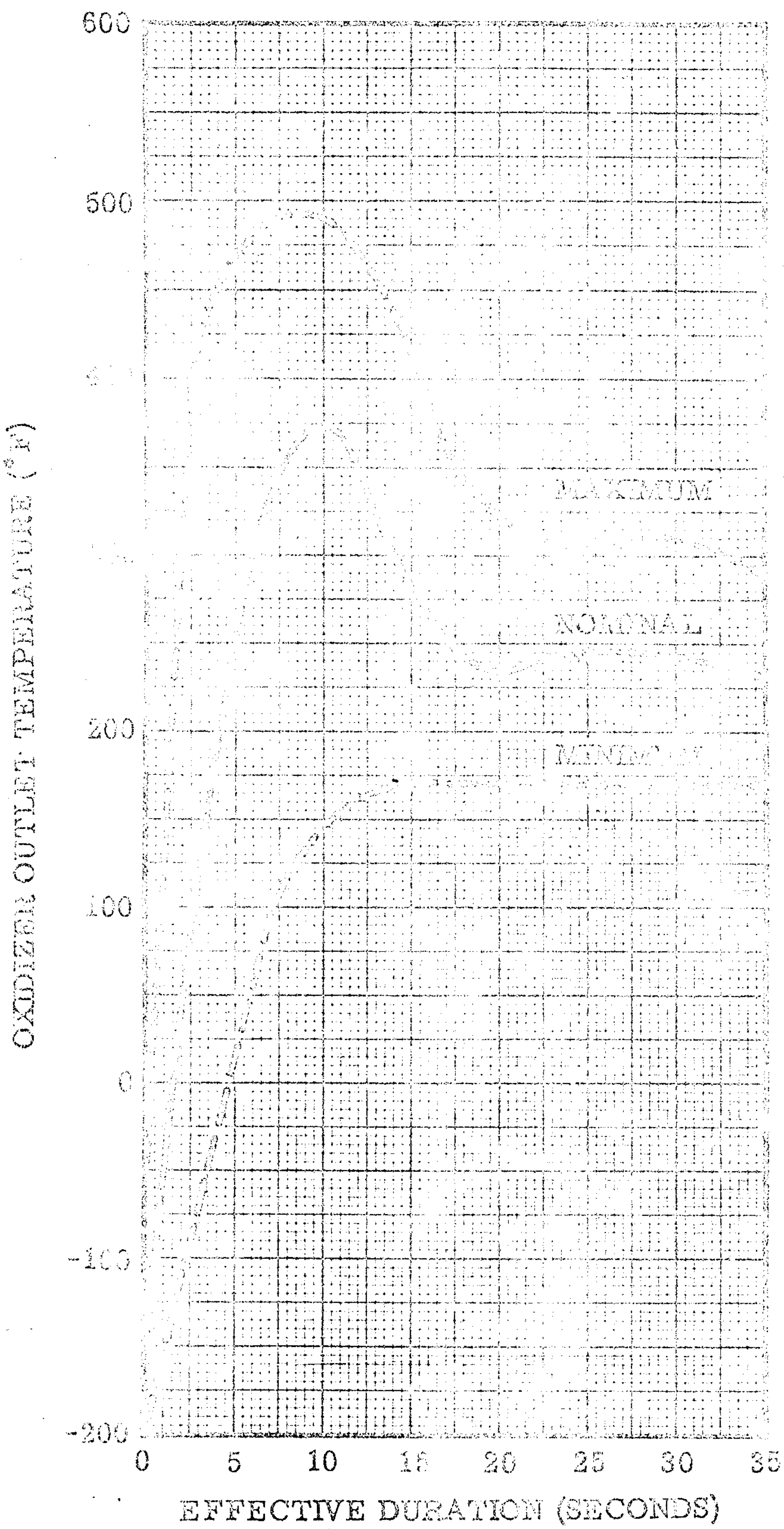


Figure 2-9K. Estimated Oxidizer Outlet Temperature Transient for Heat Exchanger

LIST OF EFFECTIVE PAGES

NOTE. The portion of the text affected by the changes is indicated by a vertical line in the outer margins of the page.

TOTAL NUMBER OF PAGES IN THIS PUBLICATION IS 228 CONSISTING OF THE FOLLOWING:

Page No.	Change No.	Issue
Title	12	....12 Ma[illegible]
A	12	....12 May 72
i thru ii	10	....16 Jul 71
iii	9	....4 Nov 70
iv	10	[illegible]
v	12	[illegible] 72
vi thru vii	10	[illegible]
viii	12	....[illegible]2 May 72
ix	9	[illegible] 70
x	10	[illegible] Jul 71
xi	11	[illegible]
xii	7	[illegible] Aug [illegible]
xiii	12	[illegible]
xiv	11	[illegible]
xv	7	[illegible] 69
xvi	12	[illegible] 72
xvii	[illegible]	[illegible] Aug 69
xviii	[illegible]	4 Nov 70
xix	10	[illegible] Jul 71
xx	12	[illegible] May 72
1-1	10	....16 Jul 71
1-2 thru 1-4	[illegible]	....4 Nov 70
1-5	[illegible]	....18 Aug 69
1-6 thru 1-6B	[illegible]	[illegible]
1-7	[illegible]	....18 Aug 69
1-8	10	[illegible] 71
1-9 thru 1-9B	8	[illegible]
1-10 thru 1-11	[illegible]	[illegible] 70
1-12 thru 1-14	[illegible]	[illegible] 69
1-15	8	....9 Feb 70
1-16	10	[illegible]
1-16A thru 1-16B	8	[illegible]
1-17 thru 1-18	8	[illegible] 70
1-19	10	[illegible] 71
1-20	8	[illegible] 70
1-21	10	[illegible] 71
1-22 thru 1-24	7	[illegible] Aug 69
1-25	10	[illegible] 71
1-26 thru 1-29	8	....9 Feb 70
1-30 thru 1-33	9	[illegible] Nov 70
1-3[illegible]	7	[illegible] Aug 69
1-[illegible]	10	....16 Jul 71
1-3[illegible]	7	....18 Aug 69
1-37	10	....16 Jul 71
1-3[illegible] thru 1-42	7	....18 Aug 69
1-[illegible]	9	....4 Nov 70
1-4[illegible]	7	....18 Aug 69
1-4[illegible]	9	[illegible] Nov 70
1-4[illegible]	7	[illegible] 69
1-[illegible]	9	[illegible] Nov 70
1-[illegible]	7	[illegible] 69
1-[illegible] 8B	9	....4 Nov [illegible]
1-[illegible] 1-50	7	[illegible] Aug [illegible]
1-[illegible]	10	....16 Jul [illegible]
1-[illegible]-62	7	....18 Aug 69
1-[illegible] 1-79	9	....4 Nov 70
1-80	10	....16 Jul [illegible]
1-[illegible] 1-84	[illegible]	....4 N[illegible]
2-1 [illegible]	10	....16 Jul 71
2-3	9	....4 Nov 70
2-4 thru 2-5	4	....13 Feb 68
2-6	9	....4 Nov 70
2-7 thru 2-8	6	....Original
2-8A thru 2-8B	5	....11 Mar 68
2-8C thru		
2-8E/2-8[illegible]	[illegible]	....4 Nov 70
2-8G thru 2-8H		
Deleted	9	....4 Nov 70
2-9 thru 2-[illegible]	7	[illegible]
2-[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
2-12 thru 2-15	12	[illegible]
[illegible]	[illegible]	[illegible]
2-1[illegible] thru		
2-17/2-18	[illegible]	[illegible]
2-19/2-20 Deleted	[illegible]	[illegible]
2-21 thru 2-22		
Deleted	[illegible]	[illegible]
2-23	[illegible]	[illegible]
2-24	6	[illegible]
2-25 thru 2-28	9	[illegible] Nov 70
2-29	[illegible]	[illegible]
2-30 thru 2-33	9	[illegible] Nov 70
2-34	[illegible]	[illegible]
2-3[illegible]	[illegible]	[illegible]
2-3[illegible]	[illegible]	[illegible] Aug 68
2-37 thru 2-38	4	[illegible] Feb 68
2-39 thru 2-[illegible]		
Deleted	[illegible]	[illegible]
2-47	[illegible]	[illegible]
2-4[illegible]	10	[illegible]
2-4[illegible] thru 2-50	9	[illegible]
2-5[illegible]	12	[illegible]
2-5[illegible]	[illegible]	[illegible]
[illegible]	12	[illegible]
2-[illegible]	9	[illegible]
2-[illegible] thru 2-[illegible]	[illegible]	[illegible]
2-57 thru 2-7[illegible]	9	[illegible]
2-7[illegible]/2-7[illegible]	2	[illegible]
[illegible]	10	[illegible] Jul 71
[illegible]	6	[illegible] Aug [illegible]
[illegible]	4	....13 Feb [illegible]
3-[illegible]	9	[illegible] Nov 70
3-5 thru		
3-6A/3-6B	10	....16 Jul 71
3-7 thru 3-10	10	....16 Jul 71
3-11 thru 3-16		
Deleted	9	....4 Nov 70
3-17/3-18	7	....18 Aug 69
3-19 thru 3-20	7	....18 Aug 69
3-21	9	....4 Nov 70
3-22	10	....16 Jul 71
3-23 thru 3-24	0	....Original
3-25 thru		
3-27/3-28	9	[illegible] Nov 70
3-29 thru 3-38		
Deleted	9	[illegible]
3-39 thru 3-41	12	[illegible]
3-[illegible]	9	[illegible]
3-43 thru		
3-44B	12	[illegible] 72
3-45	12	[illegible] 72
3-46	9	[illegible] Nov 70
3-47 thru 3-54		
Deleted	9	[illegible] Nov 70
3-55 thru		
3-57/3-58	6	....1[illegible] Aug 68
A-1/A-2	10	....16 Jul 71

Upon receipt of the second and subsequent changes to this technical manual, personnel responsible for maintaining this publication in current status will ascertain that all previous changes have been received and incorporated. Action should be taken promptly if the publication is incomplete.

This page reflects the current status of the complete manual. All pages listed m[illegible] the manual to make this publication current and complete.

TABLE OF CONTENTS

Underlined numbers denote figures.
Underlined titles denote primary paragraphs.

TABLE OF CONTENTS
(continued)

Underlined numbers denote figures.
Underlined titles denote primary paragraphs.

TABLE OF CONTENTS
(continued)

Underlined numbers denote figures.
Underlined titles denote primary paragraphs.

TABLE OF CONTENTS
(continued)

Underlined numbers denote figures.
Underlined titles denote primary paragraphs.

TABLE OF CONTENTS
(continued)

Underlined numbers denote figures.
Underlined titles denote primary paragraphs.

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS
(continued)

LIST OF ILLUSTRATIONS
(continued)

INTRODUCTION

This manual is one of seven R-3896-series technical manuals prepared to provide official Rocketdyne field support documentation for the operation and maintenance of the F-1 Rocket Engine, Part Number 104001, Serial Numbers F-2029 through F-2098, and its related ground support equipment, designed and manufactured by Rocketdyne, a division of North American Rockwell Corporation, 6633 Canoga Avenue, Canoga Park, California 91304. The information in these manuals was prepared by Logistics Publications & Training Department of Rocketdyne.

This manual contains engineering data detailing engine operation and engine system functions. For stage design criteria, refer to F-1 Engine Interface Document R-6749.

Five F-1 rocket engines are installed on the S-IC stage. Figure 1 shows engine positions relative to stage positions and fin locations.

The instructions in the manuals are used more effectively when each manual is current and complete (see figure 2) and the purpose and scope of each manual is known. The manuals that complete this series, and the nature of the data each provides, are found in the manuals contents and support functions chart.

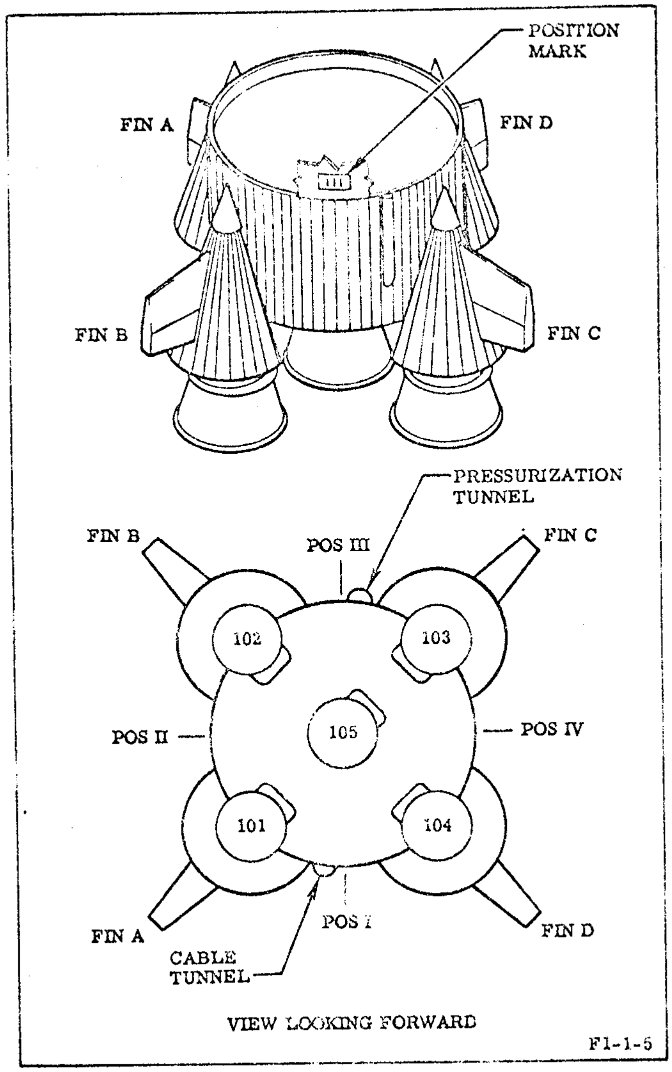


Figure 1. F-1 Rocket Engine and S-IC Stage Positions

1. F-1 MANUALS--THEIR SUPPORT FUNCTIONS.

The contents and support function chart lists all F-1-series technical manuals, describes the support function each manual serves, and lists the section titles of each manual. The chart also explains how the technical data in each manual relates to the support of the engine and its ground support equipment throughout a normal engine flow, as well as during unscheduled maintenance tasks. Information appearing in one manual is not duplicated in another. Thus, information on the description, operation, and maintenance of ground support equipment is in R-3896-5. However, the instructions for servicing the engine using ground support equipment are in R-3896-3 and R-3896-11.

Manual	Contents and Support Function	Section and Title
R-3896-1 F-1 Rocket Engine Data	This manual contains a physical description of the various F-1 engine systems and the individual engine system components, a description of the flow the engine follows from the time it is accepted by the Customer through Apollo/ Saturn V launch; data pertaining to engine design characteristics including environmental conditions, attitude, mass properties data, turbopump inlet propellant conditions, and interface connections for mating the engine with the S-IC of the Saturn V vehicle; and nominal engine performance characteristics, methods for predicting engine variable characteristics, and other pertinent information that can be used as an aid for analyzing and/or determining specific engine performance. The manual serves to familiarize the reader with the design and operation of the F-1 engine and serves as a training aid document.	See detailed table of contents for this manual.
R-3896-3, Volume I F-1 Rocket Engine Maintenance and Repair	This manual contains general maintenance practices that are peculiar to the engine covered in this volume and to the component repair procedures contained in Volume II of this manual; the use of engine, thrust chamber, and nozzle extension ground support equipment and the tasks necessary to prepare the equipment for maintenance using the applicable pieces of ground support equipment; detailed procedures for component removal, reinstallation, or replacement; and the post-installation test requirements that will verify the integrity of engine systems affected by the removal of individual engine components and	I General Maintenance and Repair II Handling III Component Removal and Installation IV Post-Maintenance Test Requirements

Manual	Contents and Support Function	Section and Title
R-3896-3, Volume I (cont)	lines. This volume and Volume II provide the necessary maintenance and repair data to perform unscheduled maintenance tasks on an uninstalled engine and the required post-maintenance tests to determine that the engine is in an operable condition.	
R-3896-3, Volume II F-1 Rocket Engine Maintenance and Repair	This manual contains cleaning, inspecting, repairing, and testing procedures for the individual engine components. This manual provides the data to restore and/or maintain components of the engine in an operable condition for reinstallation on the engine or assignment as a spare.	I Quick-Disconnect II Gas Generator III Gas Generator Ball Valve IV Gas Generator Injector Purge and Pump Seal Purge Check Valve V Deleted VI Heat Exchanger VII Heat Exchanger Check Valve VIII Thrust Chamber (Installed) IX Thrust Chamber (Uninstalled) X Thrust OK Pressure Switch XI Inert Prefill Check Valve XII Oxidizer Dome Purge Check Valve XIII Oxidizer Valve XIV Fuel Valve XV Turbopump XVA Turbine XVI Bearing Coolant Control Valve XVII Deleted XVIII Electrical Harness XIX Hypergol Manifold XX Ignition Monitor Valve XXI Checkout Valve XXII Engine Control Valve XXIII Four-Way Solenoid Valve XXIV Thrust Chamber Nozzle Extension XXV Pressure Transducer XXVI Temperature Transducer XXVII Flight Instrumentation Junction Boxes XXVIII Rigid Ducts, Flexible Lines, and Braided Flex Hoses XXIX Redundant Shutdown Valve XXX Volumetric Liquid Oxygen Transducer (Oxidizer Flowmeter) XXXI Gimbal Boot, Insulation Boot, and Insulation Seal

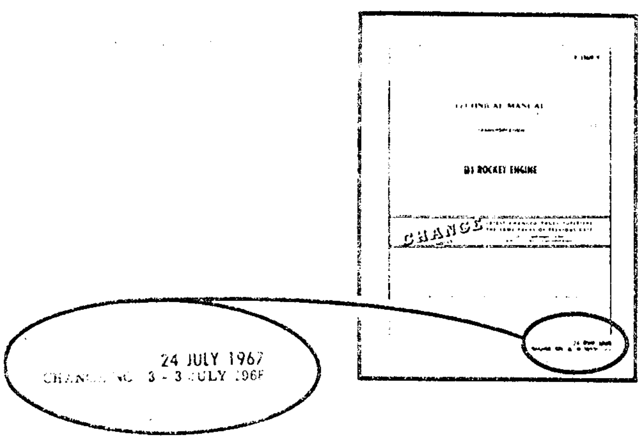
Manual	Contents and Support Function	Section and Title
R-3896-4 F-1 Rocket Engine Illustrated Parts Breakdown	This manual contains illustrative and columnar listings of all parts of the engine that can be disassembled, reassembled, repaired, replaced, or overhauled. This manual locates and identifies the interrelationship of parts, aids in the requisition of replacement parts, and indicates part usage and interchangeability and recommended repair or replacement for the F-1 engine and its individual components and parts.	I Introduction II Group Assembly Parts List III Numerical Index
R-3896-5, Volume I F-1 Rocket Engine Ground Support Equipment Maintenance and Operation	This manual contains safety requirements and general maintenance practices peculiar to the equipment covered in this volume and to equipment and T-tools covered in Volume II of this manual and includes inspection requirements, physical description, operation, intended usage, operating limitations, periodic maintenance, and parts listings with maintenance-level codes for the F-1 engine ground support equipment covered in this volume. This volume provides data to restore and/or maintain the F-1 rocket engine ground support equipment in an operable condition.	I Safety Requirements, General Maintenance, and Handling and Shipping Equipment II Hydraulic Pumping Unit G2025 III Hydraulic Pumping Unit G2026 IV Accumulator Unit G2027 V Engine Checkout Console G3142 VI Pneumatic Flow Monitors G3130 and G3131 VII Engine Vertical Installer G4049 VIII Engine Rotating Sling G4050 IX Flight Combustion Monitor 703227 X Components Test Console G3141 and Components Adapter Set G3143 XI Cryogenic Supply Unit G3146 XII Pneumatic Flow Testers G3104 and G3104MD1 XIII High-Voltage Igniter Tester G3153 and Inert Igniter 9026622 XIV Impact Recorder Unit G4090 and 99-9014031 XV Components Welding Sets 9026560, 9026561, and 9026570

Manual	Contents and Support Function	Section and Title
R-3896-5, Volume II F-1 Rocket Engine Ground Support Equipment Maintenance and Operation	This manual contains inspection requirements, physical description, operation, intended usage, operating limitations, periodic maintenance, and parts listing with maintenance-level codes for the F-1 engine ground support equipment end items that are considered tools (ie, test kits, sets, and tools) and T-tools. This volume provides data necessary to determine that those items of ground support equipment covered by this volume and the F-1 field T-tools are in an operable condition.	I Test Kits, Sets, and Tools II T-Tools III Dummy Weight T-Tools
R-3896-6 F-1 Rocket Engine Thermal Insulation Installation and Repair	This manual contains a description of the thermal insulation panels, special tools and equipment, installation and removal procedures, access provisions, repair data, and applicable packaging, storage, and handling information. This manual provides information pertinent to the maintenance and repair of F-1 engine thermal insulation.	I Description II Special Tools and Equipment III Installation and Removal (Engines F-2003 Through F-2016) IV Installation and Removal (Engines F-2017 and Subsequent) V Access Provisions VI Repair VII Storage and Handling
R-3896-9 F-1 Rocket Engine Transportation	This manual contains procedures for preparing the F-1 rocket engine, nozzle extension, thermal insulation, and miscellaneous engine loose equipment for shipment, and procedures for shipping by truck, air, or water. Included are recommended truck-, air-, and water-transport checklists, which may be used to make sure that procedures and in-transit inspection have been performed.	I Preparation for Shipping II Shipping by Truck Transport III Shipping by Air Transport IV Shipping by Water Transport
R-3896-11 F-1 Rocket Engine Operating Instructions	This manual contains complete, authorized field operating requirements that affect F-1 flight engines F-2029 through F-2098 during normal operational flow from engine receipt at MAF through vehicle launch. Specific and general requirements and procedures for normal F-1 engine activities are provided and include acceptability criteria and limits, special constraints, safety precautions, and correct sequences required to satisfactorily accomplish the activities	I Operating Requirements II General Requirements III Operating Procedures

USE YOUR MANUAL ONLY IF CURRENT AND COMPLETE

Manuals that are not current and complete are not authoritative documents and are not to be used. The following outlines the method for determining whether your manual is current and complete.

A. DETERMINING CURRENCY. To be sure that yours is the latest issue of the manual, refer to Configuration Identification & Status Report , which is revised monthly and lists the technical manual numbers, titles, unincorporated supplements, and latest change or revision dates. Your manual must have a title page with the same or later date than the date shown in the Configuration Identification & Status Report. Your manual must also include the unincorporated supplements listed in the Configuration Identification & Status Report, or if your manual is later than shown in the report, the unincorporated supplements listed in the Manual Data Supplement Record in your manual. If your title page incorporates two dates as illustrated below, compare the change (lower) date. If your manual is not current, obtain a current copy through your technical manual supply system.

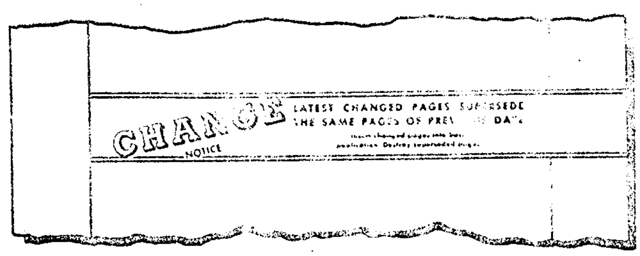


B. DETERMINING COMPLETENESS. To be sure that your manual is complete, make a page-by-page comparison of its pages to those listed in the List of Effective Pages. The List of Effective Pages, which shows the change status since the basic issue or last revision, is found on the alphabetically lettered page(s) immediately following the title page. All pages, except supplements, are listed with their issue dates. Manual pages that are dated must have the same date as that appearing in the List of Effective Pages for that page. Unchanged pages are listed as "original" and are not dated.

HOW TO KEEP YOUR MANUAL UP-TO-DATE

As design changes are made in the rocket engine and ground support equipment and better methods of maintenance are discovered, your manual is periodically changed, revised, or supplemented. The following steps will help you keep your manual up-to-date.

A. CHANGES. Updating by adding to or partially replacing existing pages is defined as a change. Changes can be identified by the change notice on the new title page.



To collate a change, refer to the Filing Instructions sheet issued with the manual and proceed as follows:

1. Remove the pages listed in the "Remove" column of the Filing Instructions sheet from the manual and destroy them. Do not concern yourself with the data on the opposite side of the deleted page since, if this date is not deleted, it is replaced in the change package.

2. Insert all pages listed in the "Insert" column of the Filing Instructions sheet in sequence. Pages with a suffix letter are inserted in alphabetical order following the page with the same basic number; for example, pages 3-14A, 3-14B, etc, follow page 3-14.

GEN-NASA-1A

Figure 2. How to Maintain Your Manual (Sheet 1 of 2)

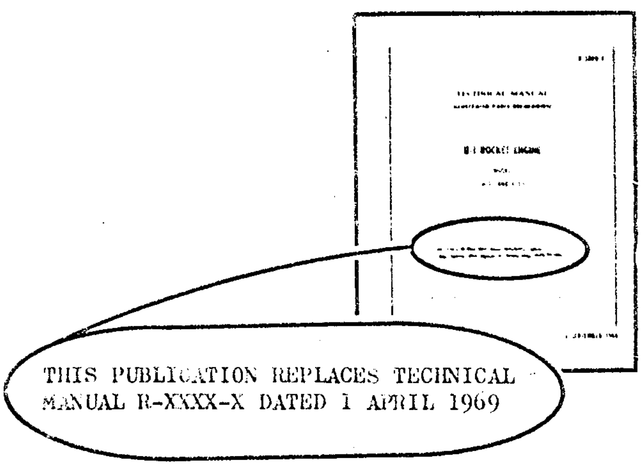
3. If you are unsure of the status of any page or pages, refer to the List of Effective Pages and make sure your manual contains pages (with the corresponding change dates) listed in the List of Effective Pages.

4. Remove manual supplements that have been incorporated.

NOTE

Incorporated supplements can be determined by reviewing the newly issued Manual Data Supplement Record.

B. REVISIONS. Updating by replacing all the existing pages of a manual is defined as a revision. Revisions can be identified by the replacement notice on the new title page.



To collate a revision, proceed as follows:

1. Remove and destroy all existing pages of your manual except Manual Data Supplements that have not been incorporated.

NOTE

Unincorporated supplements can be identified by reviewing the Manual Data Supplement Record supplied in the revision.

2. Insert the new pages in your cover.

C. SUPPLEMENTS. Updating that authorizes the addition to, or alteration of, the existing data in your manual is defined as a Manual Data Supplement. Information on how to insert supplements is found in the supplements.

HOW TO KEEP ABREAST OF THE LATEST CHANGES TO TECHNICAL DATA

Changes and/or additions to technical data are identified by a vertical bar (change bar) in the margin of the page adjacent to the changed data. A direct comparison between the new (identified by the change bar) and the old data will help you in identifying specific changes made.

GEN-NASA-2

Figure 2. How to Maintain Your Manual (Sheet 2 of 2)

2. CONFIGURATION IDENTIFICATION.

EQUIPMENT CONFIGURATION. The MD identification symbol and the equipment model designation indicate the configuration of the equipment and distinguish it from models incorporating different changes and from basic models. A basic, unchanged configuration of the equipment has no MD identification symbol. MD identification sumbols are added as changes affecting configuration are incorporated into the equipment. The MD identification symbol is stamped on the MD plate, which is mounted near the engine nameplate.

MD IDENTIFICATION SYMBOLS. On MD identification plate RD171-1022-0001, the identification symbol is a composite number representing all the changes affecting configuration (MD changes) incorporated or not incorporated into the equipment. The symbol represents a consecutively numbered series of MD changes. Any MD change, or series of MD changes, not incorporated is represented by an "X." Multi-digit numbers are underlined. Two figures together represent the limits of a series of incorporated MD changes. Figure 3 illustrates how MD changes incorporated in the engine are represented by the MD identification symbol.

MD identification plates RD171-1052-0001 through -0006 have preprinted numbers from 1 through 100 on the -0001 plate, 101 through 200 on the -0002 plate, etc. Modifications that are incorporated into the equipment are represented by the letter P (production) or K (kit) stamped in the square directly to the right of the applicable number. Omission of a P or K, indicates that the MD change is not incorporated. A P or K with a bar (-) marked through the letter (~~P~~, ~~K~~) indicates a MD change deleted in its entirety by the incorporation of a later MD change. Figure 3 illustrates how MD changes incorporated into the equipment are represented by the MD identification symbol.

MANUAL REFERENCE. A reference that appears in the manual may refer to a series of MD changes or to an individual MD change; for example, "MD9" refers to MD1 through MD9, but "MD9 change" refers to the individual MD change 9. This latter type of reference, which is illustrated in figure 3, identifies separate sets of information required by differences in configuration. When an MD reference appears in this manual, examine the MD identification symbol on the equipment to determine which set of information is applicable.

3. CONFIGURATION CHANGES--MANUAL EFFECTIVITY.

All approved ECPs (Engineering Change Proposals) and associated MD numbers applicable to the equipment covered in this manual are listed in figure 4. The date in the last column is the publication date of the manual during which the change made by the ECP was incorporated. When N/A is entered, the ECP does not change the data in the manual. Engine configuration information is in R-5857, Saturn F-1 Configuration Identification & Status Report. Engine serial numbers within this manual are in accordance with Rocketdyne F-1 engine designation. For F-1 engine serial number allocation, refer to the cross-reference index in R-5857.

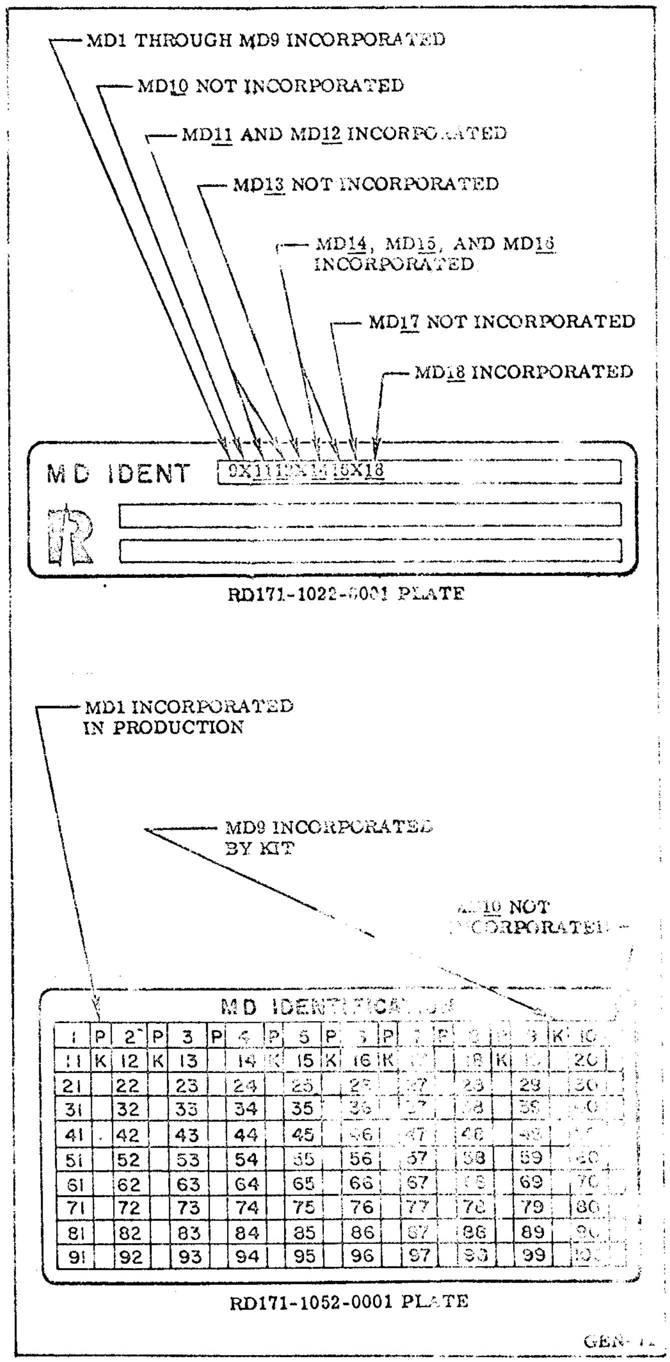


Figure 3. MD System

Approved ECP No.	MD No.	Incorporated in Manual Dated
F1-38	37	17 May 1965
F1-38R1	--	N/A
F1-39	11	8 June 1964
F1-40	--	N/A (superseded by F1-254)
F1-42	7	8 June 1964
F1-45	7	8 June 1964
F1-56	7	8 June 1964
F1-57	7	8 June 1964
F1-59	7	8 June 1964
F1-60	16	N/A
F1-62	7	8 June 1964
F1-64	7	N/A
F1-65	7	8 June 1964
F1-67	10	8 June 1964
F1-69	7	8 June 1964
F1-71	9	8 June 1964
F1-74	7	8 June 1964
F1-76	24	27 October 1964
F1-76R1	--	N/A
F1-78	7	8 June 1964
F1-80	7	8 June 1964
F1-82	18	8 June 1964
F1-85	7	8 June 1964
F1-86	7	8 June 1964
F1-90	7	8 June 1964
F1-91	7	N/A
F1-95	7	8 June 1964
F1-97	7	8 June 1964
F1-98	20	N/A (superseded by F1-197)
F1-99	14	8 June 1964
F1-100	7	8 June 1964
F1-101	8	8 June 1964
F1-106	7	8 June 1964
F1-108	7	8 June 1964
F1-124	7	8 June 1964
F1-129	8	N/A
F1-129R1	--	N/A
F1-131	7	N/A
F1-132	7	8 June 1964
F1-135	7	8 June 1964
F1-143	11	8 June 1964
F1-143R1	--	N/A
F1-146	1	8 June 1964
F1-147	7	8 June 1964
F1-149	11	27 October 1964
F1-153	7	N/A
F1-154	7	8 June 1964
F1-166	13	8 June 1964
F1-168	8	8 June 1964
F1-169	7	8 June 1964
F1-172	7	8 June 1964
F1-174	21	N/A
F1-174R1	--	N/A
F1-176	22	N/A
F1-180	34	27 October 1964
F1-182	7	N/A
F1-185	32	11 May 1964
F1-185R1	--	N/A
F1-188	7	27 October 1964
F1-188R1	--	N/A
F1-189	7	27 October 1964
F1-191	7	27 October 1964
F1-192	46	28 September 1965
F1-192R1	--	N/A
F1-192R2	--	N/A
F1-193	7	27 October 1964
F1-193R1	--	N/A
F1-194	7	27 October 1964
F1-195	7	27 October 1964
F1-196	29	N/A
F1-197	20	27 October 1964
F1-198	26	N/A
F1-198R1	--	N/A
F1-202	7	27 October 1964
F1-206	22,66	27 October 1964
F1-206R1	--	N/A
F1-206R2	--	N/A
F1-208	33	27 October 1964
F1-214	31	28 September 1965
F1-214R1	--	N/A
F1-215	116	8 August 1966
F1-215R1	--	N/A
F1-215R2	--	N/A
F1-216	31	N/A
F1-216R1	--	N/A
F1-217	7	N/A
F1-226	35	N/A
F1-228	36	27 October 1964
F1-229	8	27 October 1964
F1-229R1	--	N/A
F1-233	38	28 September 1964
F1-235	31	N/A
F1-236	7	27 October 1964
F1-241	7	27 October 1964
F1-242	39	27 October 1964
F1-244	7	27 October 1964
F1-251	7	27 October 1964
F1-253	43	N/A
F1-254	7	27 October 1964
F1-255	42,43	N/A
F1-258	22	27 October 1964
F1-258R1	--	N/A
F1-258R2	--	N/A
F1-260	54	N/A

Figure 4. Configuration Changes--Manual Effectivity (Sheet 1 of 4)

Approved ECP No.	MD No.	Incorporated in Manual Dated	Approved ECP No.	MD No.	Incorporated in Manual Dated
F1-260R1	--	N/A	F1-313	69	28 September 1965
F1-260R2	155	N/A	F1-313R1	--	N/A
F1-261	22	17 May 1965	F1-314	31	28 September 1965
F1-262	50	N/A	F1-315	70,83	28 September 1965
F1-263	51	N/A	F1-315R1	--	N/A
F1-267	49	17 May 1965	F1-315R2	--	N/A
F1-268	59	17 May 1965	F1-316	31	8 August 1966
F1-268R1	--	N/A	F1-317	71	8 August 1966
F1-269	55	17 May 1965	F1-319	31	N/A
F1-270	47	28 September 1965	F1-320	75	8 August 1966
F1-270R1	--	N/A	F1-320R1	--	N/A
F1-270R2	--	N/A	F1-321	31	28 September 1965
F1-274	53	N/A	F1-323	84,85,86	N/A
F1-276	22	N/A	F1-323R1	--	N/A
F1-277	61	N/A	F1-323R2	--	N/A
F1-278	64	N/A	F1-323R3	--	N/A
F1-279	21	N/A	F1-324	72	28 September 1965
F1-279R1	--	N/A	F1-324R1	--	N/A
F1-2[illegible]	31	12 January 1966	F1-326	79,80,95	N/A
F1-28[illegible]	65	14 October 1966	F1-328	76	28 September 1965
F1-28[illegible]R1	--	N/A	F1-328R1	--	N/A
F1-283R2	--	N/A	F1-331	31	8 August 1966
F1-285	68	28 September 1965	F1-332	31	N/A
F1-285R1	--	N/A	F1-333	54	8 August 1966
F1-287	31	14 October 1966	F1-335	31	31 March 1967
F1-28[illegible]	31	14 October 1966	F1-342	30	N/A
F1-2[illegible]	63	N/A	F1-343	90,91	31 March 1967
F1-2[illegible]1	--	N/A	F1-347	31	31 March 1967
F1-289R2	[illegible]	N/A	F1-352	31	12 January 1966
F1-294	57	17 May 1965	F1-352R1	--	N/A
F1-294R1	--	N/A	F1-353	82	N/A
F1-294R2	--	N/A	F1-356	88,93	28 September 1965
F1-303	54	8 August 1966	F1-357	89	8 August 1966
F1-303R1	--	N/A	F1-358	31	8 August 1966
F1-304	67	N/A	F1-360	99	8 August 1966
F1-304R1	--	N/A	F1-361	92	N/A
F1-305	73	28 September 1965	F1-362	54	31 March 1967
F1-305R1	--	N/A	F1-369	94	8 August 1966
F1-[illegible]	66	N/A	F1-370	106	N/A
F1-30[illegible]R1	--	N/A	F1-370R1	--	N/A
F1-30[illegible]R2	--	N/A	F1-370R2	--	N/A
F1-3[illegible]	74	N/A	F1-370R3	--	N/A
F1-3[illegible]R1	--	N/A	F1-370R4	--	N/A
F1-[illegible]	31	N/A	F1-371	31	7 April 1966
F1-30[illegible]	77,80,95	8 August 1966	F1-372	100	31 March 1967
F1-310	78,80,95	8 August 1966	F1-372R1	--	N/A
F1-31[illegible]	31,108	28 September 1965	F1-372R2	--	N/A
F1-311R1	--	N/A	F1-378	58	N/A
F1-312	96,97	12 January 1966	F1-378R1	--	N/A
F1-[illegible]R1	--	N/A	F1-378R2	--	N/A
F1-[illegible]R2	--	N/A	F1-378R3	--	N/A
F1-312R3	--	N/A	F1-379	101	12 January 1966
F1-312R4	179	N/A	F1-379R1	--	N/A

Figure 4. Configuration Changes--Manual Effectivity (Sheet 2 of 4)

Approved ECP No.	MD No.	Incorporated in Manual Dated	Approved ECP No.	MD No.	Incorporated in Manual Dated
F1-379R2	--	N/A	F1-436	123	8 August 1966
F1-380	99	7 April 1966	F1-437	[illegible]	14 October 1966
F1-381	31	N/A	F1-437R1	--	N/A
F1-391	102,103	7 April 1966	F1-437R2	--	N/A
F1-391R1	--	N/A	F1-437R3	--	N/A
F1-392	137	31 March 1967	F1-438	131	31 March 1967
F1-392R1	--	N/A	F1-439	141	10 August 1967
F1-392R2	--	N/A	F1-439R1	--	N/A
F1-405	123	31 March 1967	F1-441	140	10 August 1967
F1-405R1	--	N/A	F1-441R1	--	N/A
F1-405R2	--	N/A	F1-441R2	--	N/A
F1-406	--	31 March 1967	F1-441R3	--	N/A
F1-407	109	31 March 1967	F1-443	[illegible]	14 October 1966
F1-407R1	--	N/A	F1-444	139	10 August 1967
F1-408	104	7 April 1966	F1-444R1	--	N/A
F1-408R1	--	7 April 1966	F1-444R2	--	N/A
F1-409	105	7 April 1966	F1-445	122	8 August 1966
F1-410	128	31 March 1967	F1-445R1	--	N/A
F1-410R1	--	N/A	F1-447	138	N/A
F1-415	107	8 August 1966	F1-447R1	--	N/A
F1-416	120	31 March 1967	F1-447R2	--	N/A
F1-416R1	--	N/A	F1-448	149	10 August 1967
F1-417	--	N/A	F1-448R1	--	N/A
F1-418	--	31 March 1967	F1-448R2	--	N/A
F1-418R1	--	N/A	F1-449	127	31 March 1967
F1-419	--	31 March 1967	F1-449R1	--	N/A
F1-419R1	--	N/A	F1-452	[illegible]	31 March 1967
F1-420	--	31 March 1967	F1-452R1	--	N/A
F1-420R1	--	N/A	F1-453	126	N/A
F1-421	--	N/A	F1-454	118	31 March 1967
F1-421R1	--	N/A	F1-454R1	--	N/A
F1-421R2	--	N/A	F1-454R2	--	N/A
F1-422	113,114	8 August 1966	F1-456	124	8 August 1966
F1-422R1	--	N/A	F1-456R1	--	N/A
F1-423	119	N/A	F1-457	136	N/A
F1-423R1	--	N/A	F1-459	130	31 March 1967
F1-424	110	8 August 1966	F1-464	--	14 October 1966
F1-424R1	--	N/A	F1-467	--	N/A
F1-426	117	8 August 1966	F1-467R1	--	N/A
F1-426R1	--	N/A	F1-468	128	31 March 1967
F1-427	111	31 March 1967	F1-470	140	10 August 1967
F1-427R1	--	N/A	F1-470R1	--	N/A
F1-427R2	--	N/A	F1-470R2	--	N/A
F1-428	87	N/A	F1-471	--	N/A
F1-428R1	--	N/A	F1-475	--	N/A
F1-430	112	8 August 1966	F1-475R1	--	N/A
F1-431	137	31 March 1967	F1-475R2	--	N/A
F1-431R1	--	N/A	F1-476	135	31 March 1967
F1-431R2	--	N/A	F1-476R1	--	N/A
F1-432	125	31 March 1967	F1-478	137	N/A
F1-432R1	--	N/A	F1-478R1	--	N/A
F1-432R2	--	N/A	F1-478R2	--	N/A
F1-434	121	31 March 1967	F1-480	132	31 March 1967
F1-434R1	--	N/A			

Figure 4. Configuration Changes--Manual Effectivity (Sheet 3 of 4)

Approved ECP No.	MD No.	Incorporated in Manual Dated	Approved ECP No.	MD No.	Incorporated in Manual Dated
F1-480R1	--	N/A	F1-535	--	N/A
F1-482	133,134,142	31 March 1967	F1-543	165	11 March 1968
F1-482R1	142	10 August 1967	F1-543R1	--	N/A
F1-495	144	10 August 1967	F1-545	154	11 March [illegible]
F1-495R1	--	N/A	F1-547	169	N/A
F1-498	145	10 August 1967	F1-54[illegible]	160	13 February 19[illegible]
F1-498R1	--	N/A	F1-5[illegible]R1	--	N/A
F1-4[illegible]	--	N/A	F1-5[illegible]	17[illegible]	[illegible]
F1-49[illegible]	137	10 August 1967	F1-552R1	--	N/A
F1-49[illegible]R1	--	N/A	F1-552R2	--	N/A
F1-500	150,151	10 August 1967	F1-579	--	[illegible]ch [illegible]68
F1-500R1	--	N/A	F1-580	--	N/A
F1-502	148	N/A	F1-581	167,168	14 July 1968
F1-504	141	31 March 1967	F1-581R1	--	N/A
F1-504R1	141	10 August 1967	F1-581R2	--	N/A
F1-50[illegible]	161	N/A	F1-581R3	--	N/A
F1-505R1	--	N/A	F1-581R4	--	N/A
F1-505R2	[illegible]	N/A	F1-586	--	N/A
F1-506	15[illegible]	13 February 1968	F1-587	--	N/A
F1-507	--	N/A	F1-590	176	18 August 1969
F1-509	14[illegible]	N/A	F1-590R1	--	N/A
F1-510	152	10 August 1967	F1-590R2	--	N/A
F1-5[illegible]	--	N/A	F1-590R3	--	N/A
F1-5[illegible]	[illegible]46	10 August 1967	F1-590R4	--	N/A
F1-5[illegible]1	--	N/A	F1-591	172	N/A
F1-[illegible]	[illegible]	10 August 1967	F1-592	173	18 August 1969
F[illegible]	--	N/A	F1-592R1	--	N/A
F1-5[illegible]	147	14 July 1968	F1-594	--	N/A
F1-51[illegible]	--	N/A	F1-594R1	--	N/A
F1-5[illegible]	1[illegible]	13 February 1968	F1-596	[illegible]	N/A
F1-5[illegible]	--	N/A	F1-596R1	--	N/A
F1-52[illegible]R2	[illegible]	11 March 1968	F1-597	175	N/A
F1-52[illegible]R3	--	N/A	F1-601	--	N/A
F1-521R4	18[illegible]	N/A	F1-602	178	N/A
F1-522	--	N/A	F1-604	180	4 November 1970
F1-523	--	13 February 1968	F1-607	181	4 November 1970
F1-524	--	13 February 1968	F1-607R1	--	N/A
F1-52[illegible]	157,158	13 February 1968	F1-607R2	--	N/A
F1-525R[illegible]	--	N/A	F1-607R3	--	N/A
F1-526	156	14 July 1968	F1-612	184,185	4 November 1970
F1-526R1	--	N/A	F1-612R1	--	N/A
F1-5[illegible]	162,163	13 February 1968	F1-612R2	--	N/A
F1-5[illegible]R1	--	N/A	F1-613	186,187	4 November 1970
F1-5[illegible]R2	--	N/A	F1-617	--	N/A
F1-530R3	--	N/A	F1-618	188,189,190	N/A
			F1-618R1	--	N/A

Figure 4. Configuration Changes--Manual Effectivity (Sheet 4 of 4)

SECTION I

DESCRIPTION AND OPERATION

1-1. SCOPE. This section contains a general description of the F-1 propulsion system and a detailed description of each subsystem and component. Engine operation from the preparation phase through and including the engine cutoff phase is defined. Also included, are external inputs necessary for engine operation, typical engine operating parameters, and a description of the flow the engine follows from the time it is accepted by the Customer through Apollo/ Saturn V launch.

1-2. F-1 ROCKET ENGINE.

1-3. The F-1 propulsion system was developed to provide the power for the booster flight phase of the Saturn V vehicle. Five engines are clustered in the S-IC stage of the Saturn V to obtain the necessary 7,610,000 pounds thrust.

1-4. The engine features a two-piece thrust chamber that is tubular-walled and regeneratively cooled to the 10:1 expansion ratio plane, and double-walled and turbine gas cooled to the 16:1 expansion ratio plane; a thrust chamber mounted turbopump that has two centrifugal pumps spline-connected on a single shaft driven by a two-stage, direct-driven turbine; one-piece rigid propellant ducts that are used in pairs to direct the fuel and oxidizer to the thrust chamber; and a hypergolic fluid cartridge that is used for thrust chamber ignition.

1-5. The engine is within an envelope of approximately 12.5 feet in diameter and 19.2 feet long and weighs approximately 18,600 pounds dry. Refer to section II for specific dimensions and weight. Thrust vector changes are achieved by gimbaling the entire engine. The gimbal block is located on the thrust chamber dome, and actuator attach points are provided by two outriggers on the thrust chamber body.

1-6. Component locations on the engine in the horizontal position are basically referenced to No. 1 (left) (figure 1-1) or No. 2 (right) (figure 1-2) sides of the engine as viewed from the exit end of the thrust chamber with the turbopump at 12 o' clock (top) and the hypergol manifold assembly at 6 o' clock (bottom). Component locations on the engine in the vertical position are referenced to the principal component on the four sides of the engine (eg, gas generator side (No. 1), engine control valve side (No. 2), turbopump side, and hypergol manifold side). A view of the forward end of the engine is shown in figure 1-3.

1-7. ENGINE PHYSICAL DESCRIPTION.

1-8. The F-1 engine is a single-start, fixed-thrust, liquid bipropellant engine calibrated to develop a sea-level-rated thrust of 1,522,000 pounds with a specific impulse (I_{sp}) of 265.3 seconds. Engine propellants are liquid oxygen and propellant [illegible] at a mixture ratio of 2.27:1. The propellant kerosene fuel is used as the working fluid for the gimbal actuators and for the engine control system and is also used as the turbopump bearing lubricant. The F-1 engine is comprised of seven operational systems:

(1) A propellant feed system, which supplies pressurized propellants for combustion and hydraulic pressure for the engine control system.

(2) An ignition system, which initiates combustion in the gas generator and the thrust chamber.

(3) A gas generating system, which produces the energy to drive the turbopump and condition propellant tank pressur[illegible].

(4) An engine control system, which regulates the start, operating level, and shutdown of the engine.

(5) A flight instrumentation system, which measures selected engine parameters for monitoring and evaluating the operational characteristics of the engine.

(6) An environmental conditioning system, which protects the engine from extreme temperature environment caused by plume radiation and backflow during flight.

(7) A purge and drain system, which inhibits contamination and facilitates the overboard disposition of expended fluids. Detailed information of the engine system and its components is in the following paragraphs. An engine fluid schematic (figure 1-4), engine leading particulars (figure 1-5), and an engine performance schematic (figure 1-5A) are included to support the text. Detailed information on engine operation is presented in paragraphs 1-121 through 1-133.

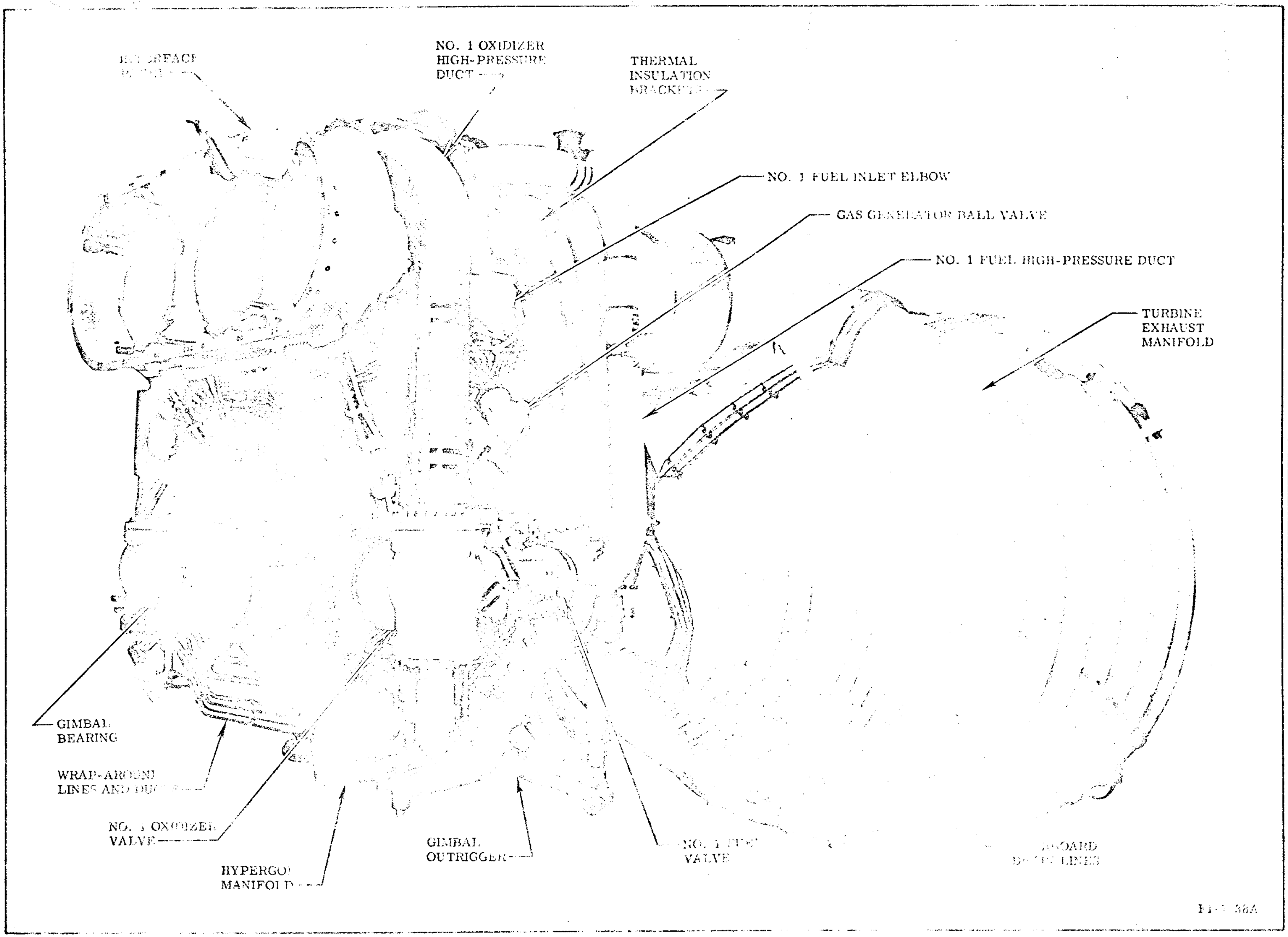


Figure 1-1. F-1 Rocket Engine, Number One Side

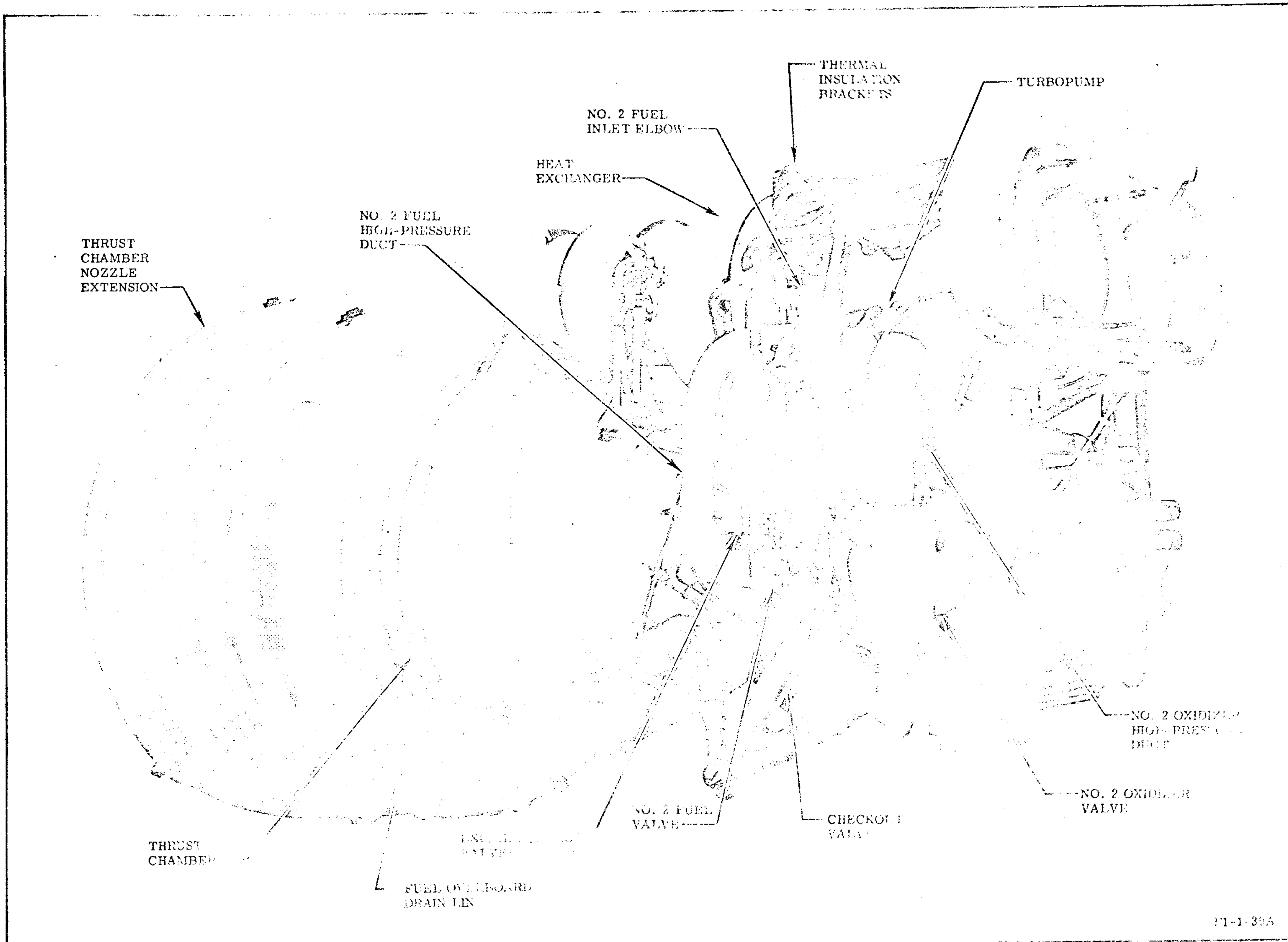


Figure 1-2. F-1 Rocket Engine, Number Two Side

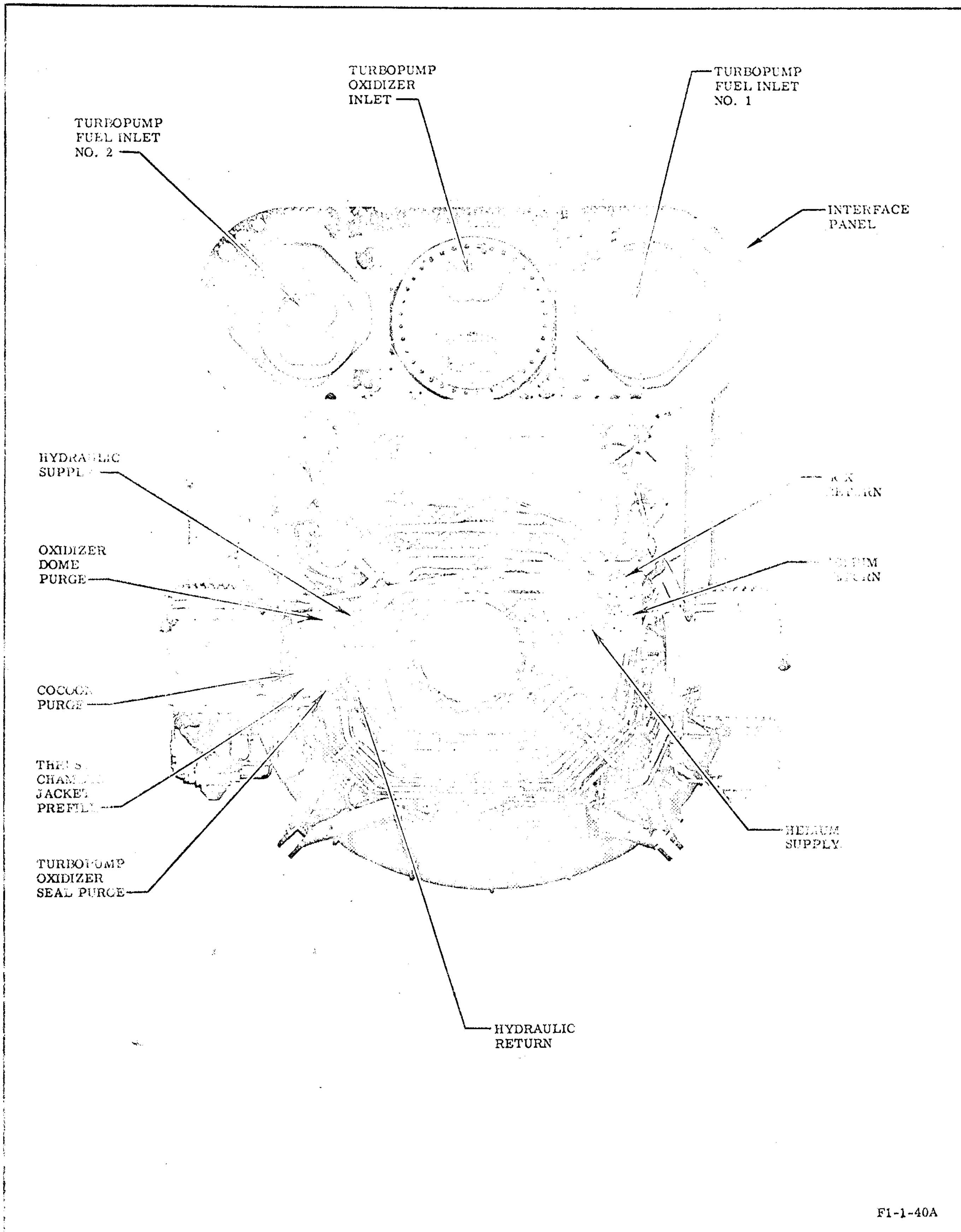


Figure 1-3. F-1 Rocket Engine, Forward End

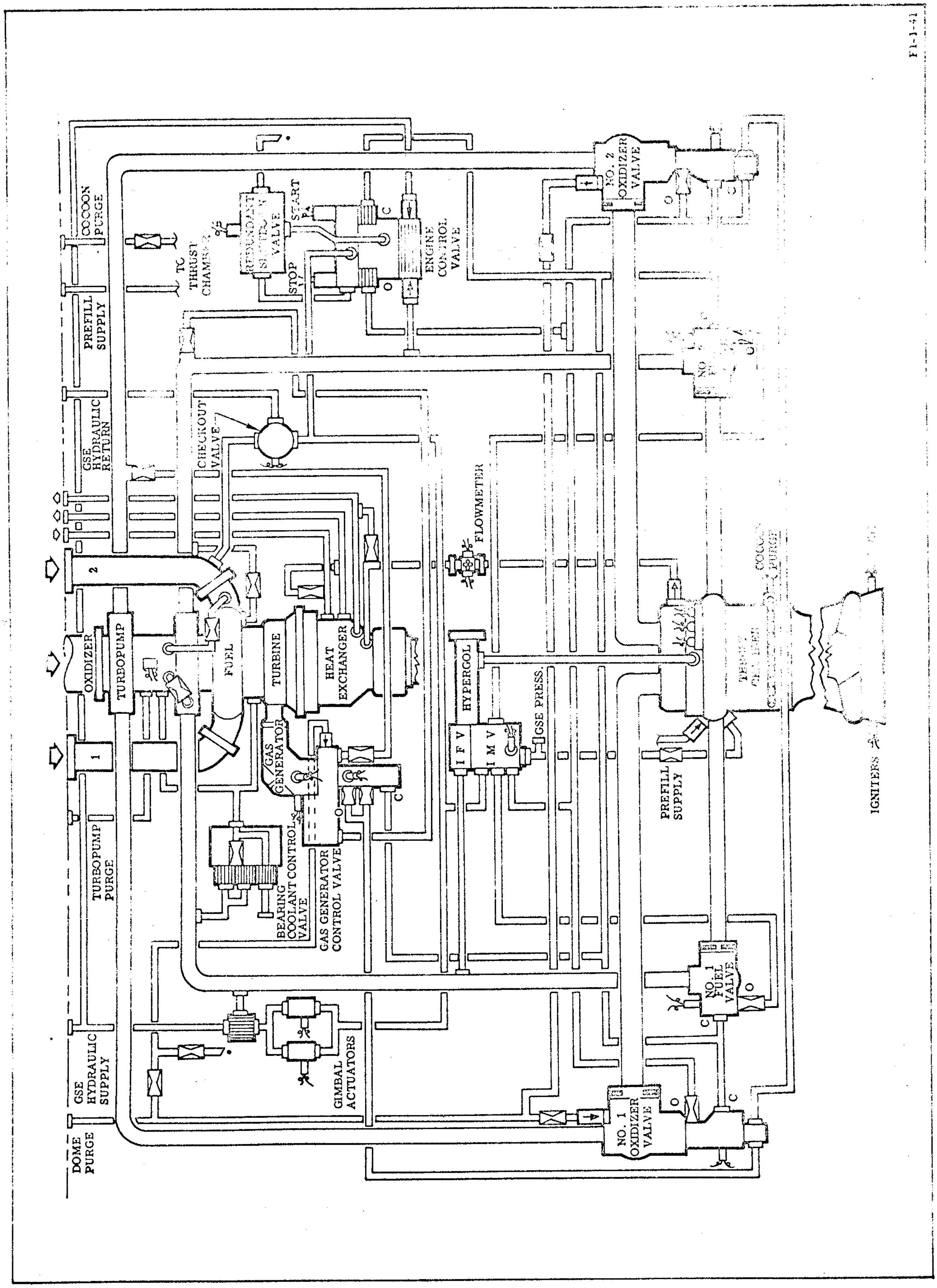


Figure 1-4. F-1 Engine Schematic

Thrust level (sea level)	1,522,000 lb
Specific impulse (sea level)	265.3 sec
Total propellant flowrate	5,737 lb/sec (40,670 gpm)
Fuel	1,756 lb/sec (15,632 gpm)
Oxidizer	3,981 lb/sec (25,038 gpm)
Mixture ratio	2.27:1
Expansion ratio	16:1
Thrust chamber pressure	1,125 psia
Thrust chamber temperature	5,970° F
Thrust chamber exit pressure (16:1)	9.6 psia
Fuel pump discharge pressure	1,870 psia
Oxidizer pump discharge pressure	1,602 psia
Gas generator flowrate (included in total)	167 lb/sec
Fuel	118 lb/sec
Oxidizer	49 lb/sec
Gas generator mixture ratio	0.416:1
Gas generator combustor pressure	980 psia
Gas generator temperature	1,453° F
Turbine speed	5,492 rpm
Time from turbopump initiation to rated speed	5.2 sec
Time from cutoff to zero rpm	3.5 sec
Turbine brake horsepower	53,146 hp
Nozzle extension coolant gas temperature	1,138° F
Hydraulic recirculation flowrate	11.6 ±1.1 gpm at 1,500 psig
Engine dry weight (average)	18,619 lb

Figure 1-5. Engine Leading Particulars (Engines Incorporating MD128 or MD174 Change)

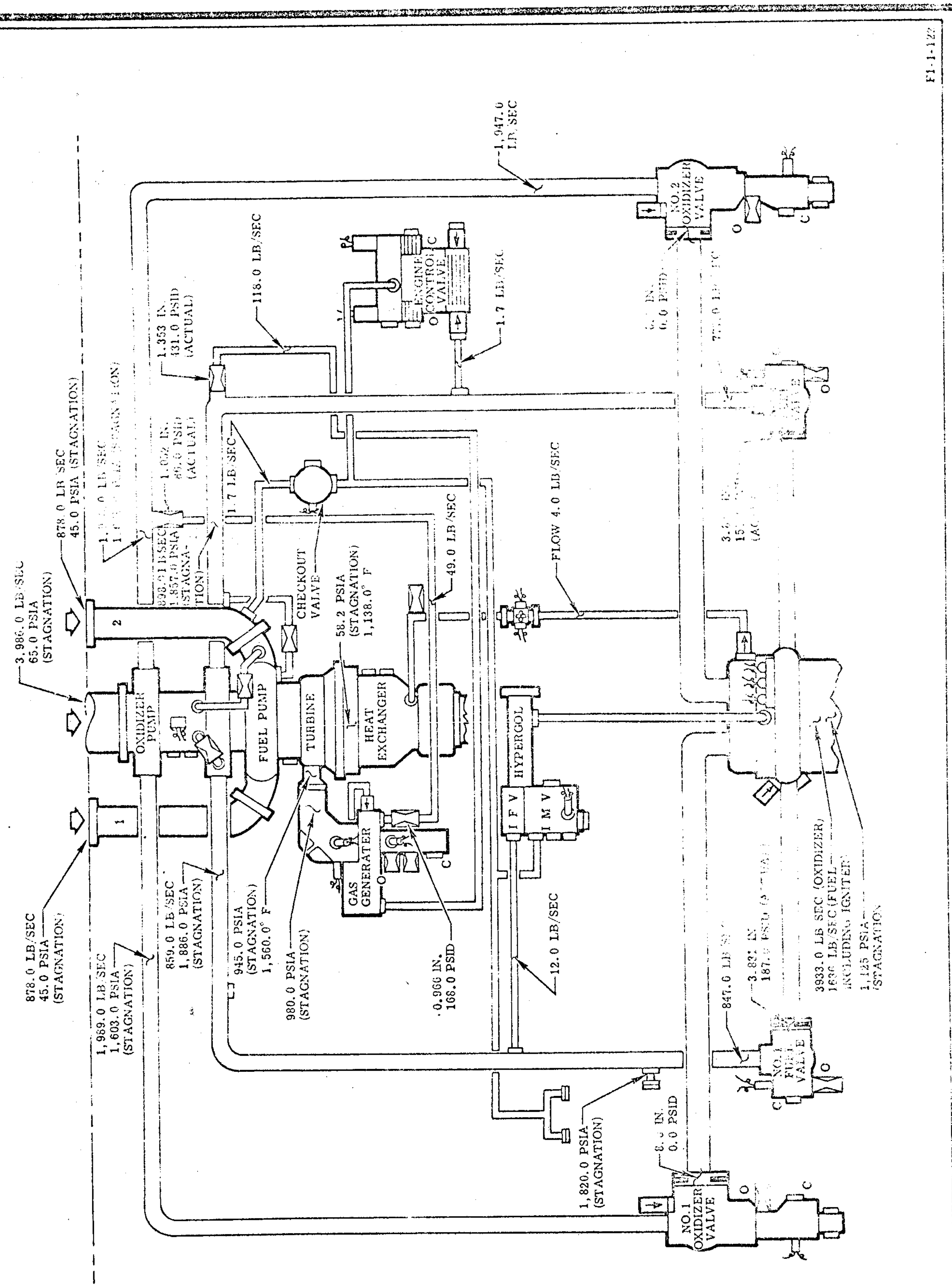


Figure 1-5A. Engine Performance Schematic (Engines Incorporating MD128 or MD174 Change)

1-9. PROPELLANT FEED SYSTEM DESCRIPTION.

1-10. The propellant feed system transfers oxidizer and fuel, under pressure, from the propellant tanks to the thrust chamber and gas generator. The system consists of the following major components: A thrust chamber, a turbopump, two oxidizer valves, two fuel valves, two high-pressure oxidizer ducts, two high-pressure fuel ducts, and two fuel inlet elbows.

1-11. THRUST CHAMBER ASSEMBLY DESCRIPTION.

1-12. The thrust chamber assembly (figure 1-6) is the engine section within which the engine thrust is developed and by which this thrust is transmitted to the thrust structure of the booster stage or test stand. The thrust is developed through the process of burning propellants in the combustion chamber and accelerating, to supersonic velocity, the gaseous products of this combustion through an expansion nozzle. The thrust is transmitted through a gimbal bearing and two gimbal actuator outrigger assemblies.

1-13 The thrust chamber assembly consists of a [illegible] thrust chamber, an injector, an oxidizer dome and manifold, and a gimbal assembly. The gimbal assembly attaches to the oxidizer dome by eight bolts. The oxidizer dome is bolted to the injector by 16 inner-dome support bolts, and both the oxidizer dome and injector are bolted to the thrust chamber body by 64 outer-dome attach bolts. The dome, injector, and thrust chamber body are indexed to each other by one diamond-shaped and one round, noninterchangeable index pin, spaced 180 degrees apart at the interface flanges below the two oxidizer dome inlets. The mating flanges of the dome and injector are sealed by a Teflon-filled Flexitallic gasket. The mating flanges of the injector and thrust chamber body are sealed at the outer diameter by a Viton-A O-ring and at the inner diameter by a hollow Inconel-X O-ring. The Inconel-X O-ring incorporates drilled holes in its outer diameter to permit injector manifold fuel pressure to enter the hollow section to increase its sealing capability. Thrust chamber leading particulars are presented in figure 1-7. Thrust chamber and nozzle extension are illustrated in figure 1-8.

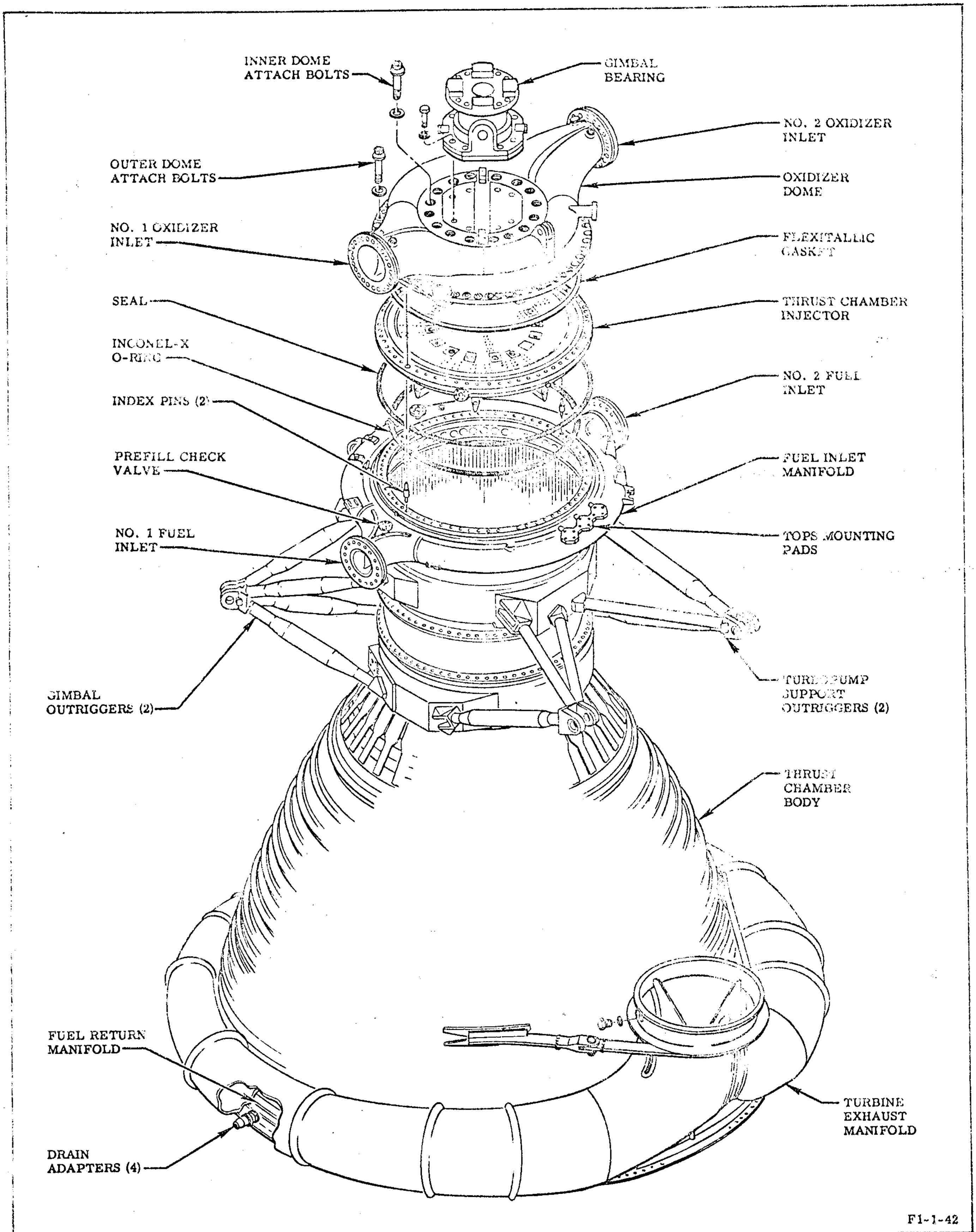


Figure 1-6. Thrust Chamber Assembly

Thrust level (sea level)	1,522,000 lb	Oxidizer dome pressure drop	57 psia
Mixture ratio	2.40:1	Fuel jacket pressure drop	244 psia
Propellant flowrates		Valves pressure drops	
Oxidizer	3,933 lb/sec	Oxidizer	91 psia
Fuel	1,636 lb/sec	Fuel	210 psia
Injector end pressure	1,125 psia		
Fuel injector manifold pressure	1,222 psia	Expansion ratios	
Exit pressure (16:1)	9.6 psia	Thrust chamber	10:1
Combustion area temperature	5,970° F	Thrust chamber and nozzle extension	16:1
Nozzle extension coolant gas temperature	1,138° F	Fuel jacket prefill	
Fuel inlet manifold pressure	1,466 psia	Solution	Ethylene glycol
		Capacity	103-105 gal.
Injector pressure drops			
Oxidizer	309 psia		
Fuel	97 psia		

Figure 1-7. Thrust Chamber Leading Particulars (Engines Incorporating MD128 or MD174 Change)

1-14. THRUST CHAMBER BODY DESCRIPTION. The thrust chamber body contains a combustion chamber for the burning of the propellants, and a nozzle of the required 10:1 expansion ratio for expelling gases produced by the burned propellants at the supersonic velocity necessary to produce the desired thrust.

1-15. The thrust chamber body is a furnace-brazed, tubular-walled, regeneratively fuel-cooled, bell-shaped chamber incorporating two outrigger arms to support the turbopump and two outrigger arms to which the gimbal actuators attach. A fuel inlet manifold and a turbine exhaust manifold are welded to opposite ends of the chamber. One hundred seventy-eight primary tubes, hydraulically formed from 1-3/32 inch outside diameter Inconel-X tubing, make up the chamber body above the 3:1 expansion ratio plane (approximately 30 inches below the throat centerline plane). Three hundred fifty-six one-inch-outside-diameter secondary tubes of the same material form the chamber from the 3:1 to the 10:1 expansion ratio plane. A raised weld bead with the tube number and a directional flow arrow, identify fuel-up tube No. 1 and fuel-down tubes No. 60 and 120 on the chamber internal faces of the injector end ring and fuel return manifold. External to the chamber the same tubes are similarly identified on reinforcing bands and straps below the thrust chamber throat.

1-16. Two secondary tubes are brazed to each primary tube at the 3:1 expansion ratio area plane. Every other primary tube is a fuel-down tube and is slotted on its outboard side at the fuel inlet manifold area into which fuel from the inlet manifold is directed. An orificed plug is brazed into the tube above the slot to permit 30 percent of the fuel to go directly to the fuel injector manifold. The remaining 70 percent of the fuel is used for regeneratively cooling the thrust chamber and is directed down the tube to the fuel return manifold at the end of the chamber. From the fuel return manifold, the fuel is directed by the adjacent fuel return tubes to the fuel injector manifold. The return manifold is welded to the bottom of the thrust chamber secondary tubes and incorporates four drain ports, located 90 degrees apart, to drain residual fluids. Forty lugs are welded to the inside wall of the return manifold for attaching the turbine exhaust leak-test fixture.

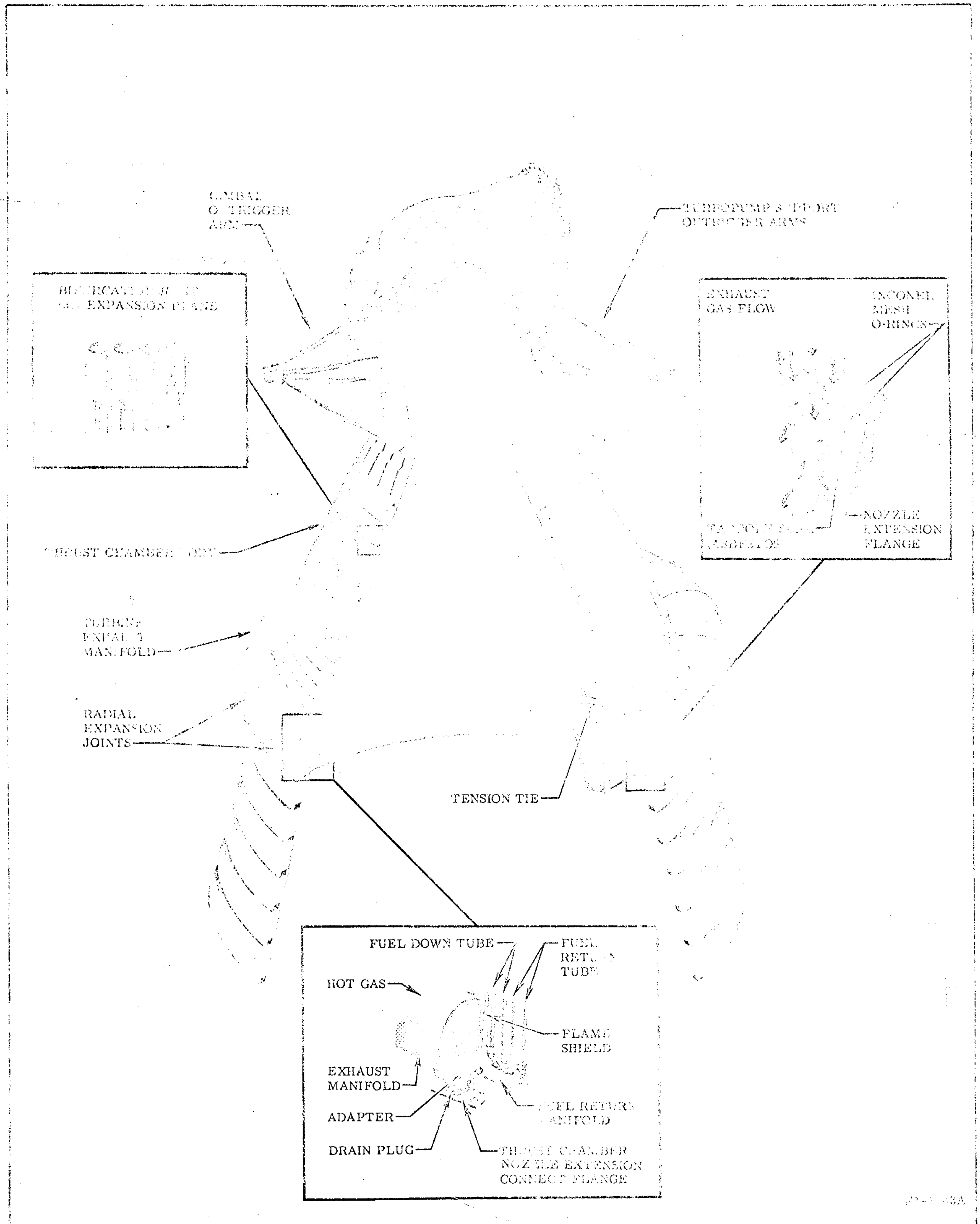


Figure 1-8. Thrust Chamber and Nozzle Extension

1-17. The fuel inlet manifold, welded to the upper end of the chamber body, incorporates two flanges, 180 degrees apart, for mounting the main fuel valves. A three-section flange for mounting the thrust OK pressure switches, and another for attaching the prefill check valve, are located on the inlet manifold. The fuel inlet manifold distributes fuel from the main fuel valves to the thrust chamber fuel-down tubes through angled, radial passages drilled through the inner wall of the manifold and alined with slots in the primary fuel-down tubes.

1-18. The turbine exhaust manifold collects and evenly distributes the turbine exhaust gas to the area between the walls of the nozzle extension. The exhaust manifold is a CRES torus of decreasing (from inlet to exit) cross-sectional area incorporating 15 omega expansion joints to compensate for thermal growth. Splitter plates at the inlet and flow vanes at the exit area contribute to the uniform distribution of the exhaust gases into the nozzle extension. The exhaust manifold is welded to a flame shield that is welded to the outer wall of the thrust chamber.

1-19. THRUST CHAMBER INJECTOR DESCRIPTION. The thrust chamber injector distributes the propellants into the combustion chamber at the proper mixture ratio, pressure, and spray pattern to initiate and sustain stable combustion. It is a CRES, 31-ring, plate-type injector divided into 13 compartments by 2 circular and 12 radial baffles, which dampen tangential and transverse combustion instability shock waves generated during combustion. The compartments are identified numerically, 1 through 13, and the baffles alphabetically, A through N. (See figure 1-9.) The 31-ring grooves consist of 16 fuel ring grooves alternating with 15 oxidizer ring grooves. The fuel ring grooves are supplied with fuel from the injector manifold by 32 radial passages, and the oxidizer ring grooves are supplied with oxidizer from the oxidizer dome by axially drilled holes. Fourteen copper rings, orifice-drilled to provide a doublet fuel-on-fuel impingement, and 2 circular, fuel-cooled copper baffles are brazed to the fuel ring grooves. Fifteen copper rings, orificed-drilled to provide a doublet oxidizer-on-oxidizer impingement, are brazed to the oxidizer ring grooves. The twelve radial, fuel-cooled, copper baffles are supplied with fuel by the outer circular baffle to which they are brazed. Two igniter fuel housings in each of the 12 outer compartments and one igniter fuel housing in the center compartment, connected by individual fuel feed tubes to the igniter manifold, inject igniter fuel to the [illegible]. The center of compartment No. [illegible] for the attachment of the throat plug shaft.

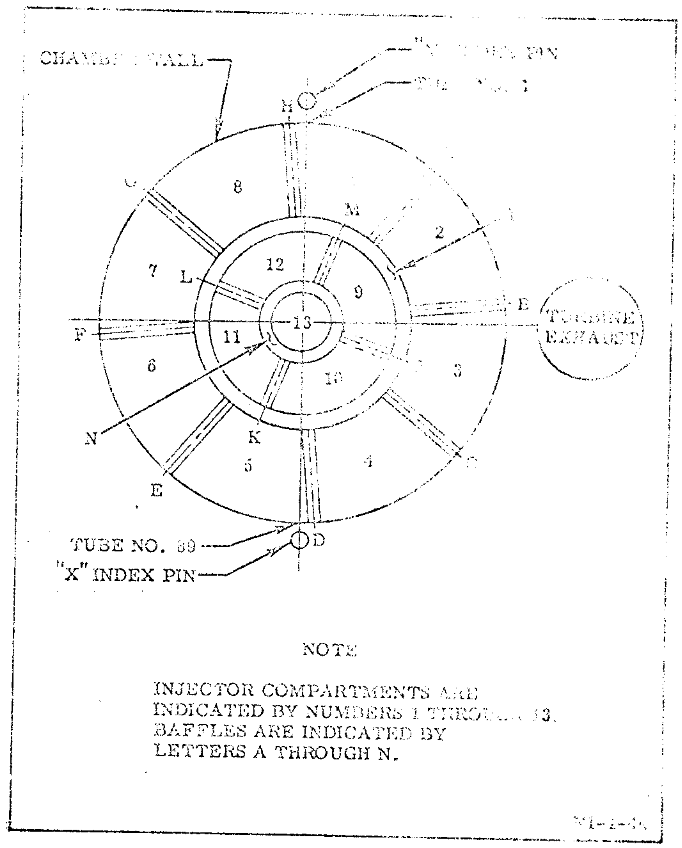


Figure 1-9. Thrust Chamber Injector Compartments and Baffles

1-20. THRUST CHAMBER OXIDIZER DOME AND MANIFOLD DESCRIPTION. The thrust chamber oxidizer dome and manifold assembly (figure 1-10) distributes oxidizer to the thrust chamber injector and provides the attach point for the gimbal assembly. The assembly is a welded, CRES and nickel-base alloy unit consisting of a dome body and a torus manifold. The dome body contains the attaching flange and support posts for interfacing with the injector, and a slotted and drilled mounting flange for interfacing with the gimbal assembly. The manifold incorporates two inlets 180 degrees apart, for mounting the No. 1 and No. 2 oxidizer valves, and a flanged boss for the heat exchanger oxidizer supply line. To prevent swirling of the oxidizer, the manifold is isolated into two compartments by two torus dams welded at 90 degrees from the inlets.

1-21. GIMBAL BEARING ASSEMBLY DESCRIPTION. The gimbal bearing assembly (figure 1-11) permits the engine assembly to be rotated about its x- and z-axes and thereby provides limited control of the engine thrust vector to enable the vehicle's guidance system to perform vehicle pitch, yaw, and roll commands. The gimbal bearing assembly is also the principal thrust interface between the engine and vehicle or test stand. The assembly is a spherical, low-friction, steel universal joint incorporating ball- and socket-type bearing surfaces. A composition of Teflon-impregnated Fiberglass (Fabroid) is bonded to the bearing surfaces of the sockets. The main components of the gimbal assembly consist of a misalinement plate, a seat, a body, a block, and a shaft. A silicone-impregnated Fiberglass boot around the gimbal bearing protects the assembly from adverse environmental conditions.

1-22. The misalinement plate is the interface between the oxidizer dome and gimbal assembly and incorporates guides and threaded-type adjustment devices to laterally position the assembly. Eight slotted holes in the plate flange, which coincide with eight threaded inserts in the dome flange, allow lateral adjustment of the plate along the x-axis. Eight oversized holes in the seat flange, coinciding with the slotted holes in the plate, allow lateral adjustment of the seat along the z-axis. The bottom guide recesses into a guide slot machined into the dome. The seat rests on the misalinement plate and has a guide slot into which the upper guide of the misalinement plate recesses. The seat contains the Fabroid-lined socket section within which the ball sections of the body move and incorporates two arms that support the shaft. The body is the engine interface to the vehicle or test stand structure. The body incorporates the ball section for the seat socket and the Fabroid-lined socket section for the ball section of the block. The block contains the ball section for the Fabroid-lined socket section of the body. The sides of the block are lined with Fabroid as are the surfaces of the hole into which the shaft fits. The shaft, through the support arms of the seat, transmits all bearing loads between the engine and vehicle. The shaft is prevented from rotating and moving axially by a plug and screw retainers. The Fabroid liners of the gimbal assembly are lubricated at assembly and require no further lubrication.

1-23. THRUST CHAMBER NOZZLE EXTENSION DESCRIPTION. The nozzle extension (figure 1-12) increases the thrust chamber expansion ratio to the ratio that provides an optimum average of engine performance over the powered phase of the booster stage trajectory. The nozzle extension is of welded construction incorporating nickle-base alloy inner and outer walls, separated by a space along with CRES reinforcing channel bands welded to the outer wall circumference. Film cooling of the inner walls is achieved by injecting turbine exhaust gases, supplied to the cavity between the walls by the turbine exhaust manifold, into the thrust chamber exhaust stream through injector slots formed by 23 rows of overlapping shingles that form the inner wall. The thrust chamber nozzle extension is bolted to the thrust chamber exit end ring after the engine is installed in the vehicle.

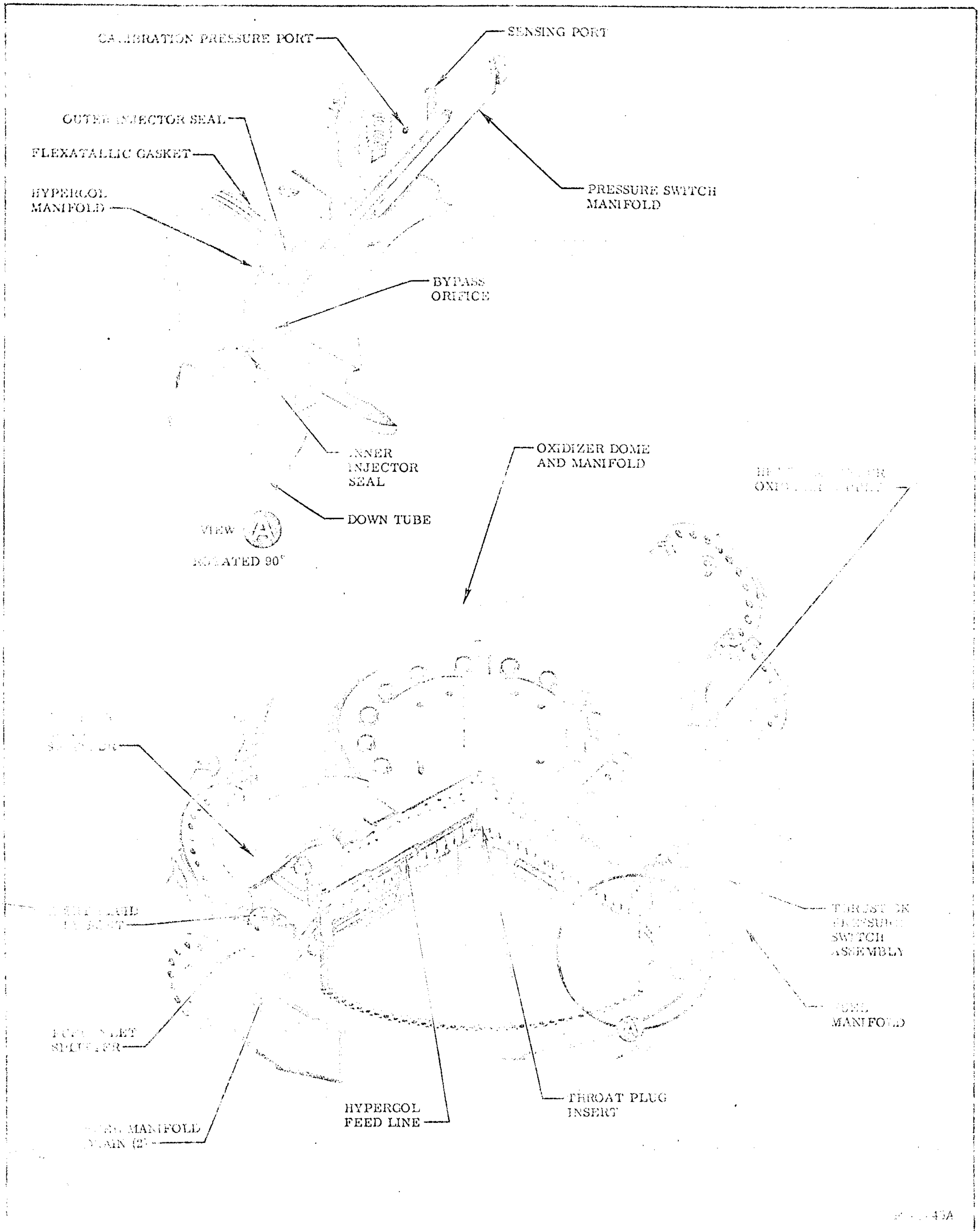


Figure 1-10. Thrust Chamber Oxidizer Dome

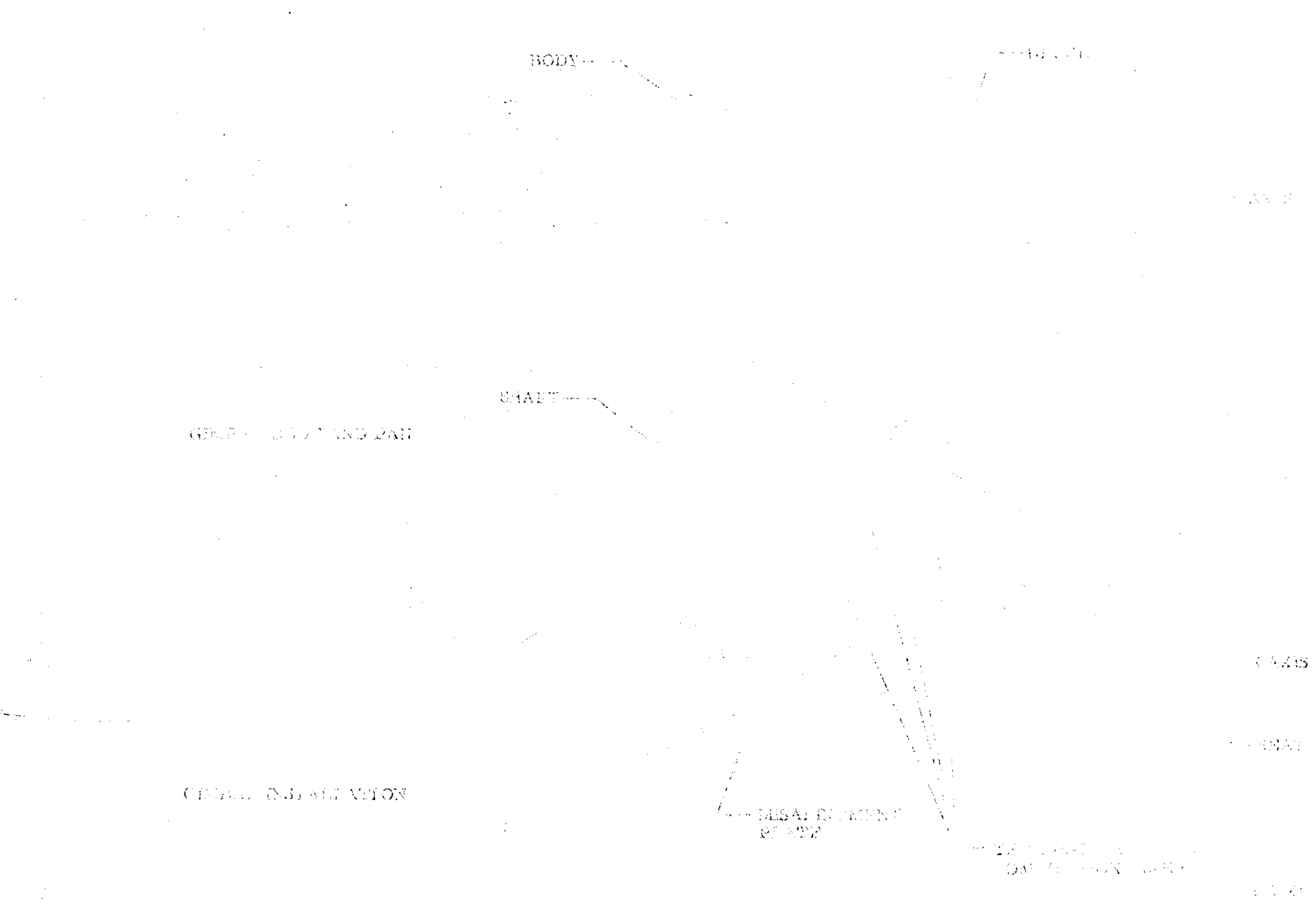


Figure 1-11. Gimbal Bearing

1-24. TURBOPUMP DESCRIPTION.

1-25. The turbopump assembly, designated the Mk-[illegible] turbopump, delivers propellants to the engine system [illegible] pressures and flowrates. The assembly is mounted parallel to the thrust chamber longitudinal centerline and is primarily supported by two three-legged outrigger assemblies welded to the chamber body and by the four high-pressure propellant ducts installed between the turbopump and the thrust chamber. The turbopump assembly (figures 1-13 and 1-14) is comprised of two centrifugal pumps, mounted back-to-back on a common shaft, directly driven by a two-stage, velocity compounded, impulse gas turbine. The main shaft and the rotating parts that attach directly to the shaft are dyna[illegible] assembly prior to final [illegible] pump [illegible] Plugs in the fuel impeller and weights [illegible] turbine wheels are installed, as required [illegible] the proper [illegible] the required [illegible] parts on each of the pump [illegible] assembly. [illegible] electrically [illegible] bearing [illegible] at the [illegible] one [illegible] cooled [illegible] at the turbine area. [illegible] for a cutaway view of the turbopump. [illegible] carbon-segmented [illegible] by plastic (Kel-F, Teflon) and [illegible] (Buna-N, Viton-A) seals, [illegible] to isolate the propellants, [illegible] hot gases to their respective areas.

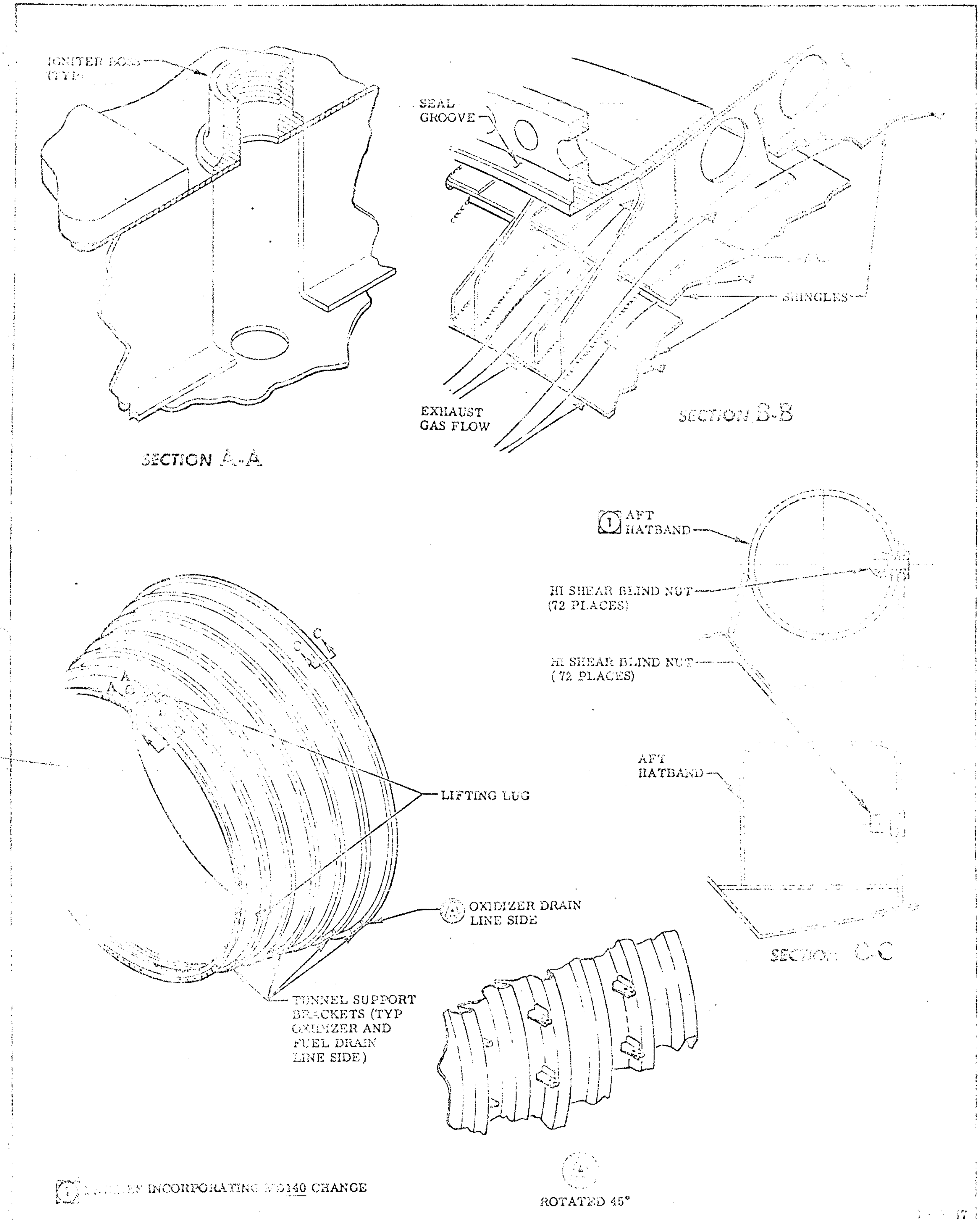


Figure 1-12. Thrust Chamber Nozzle Extension

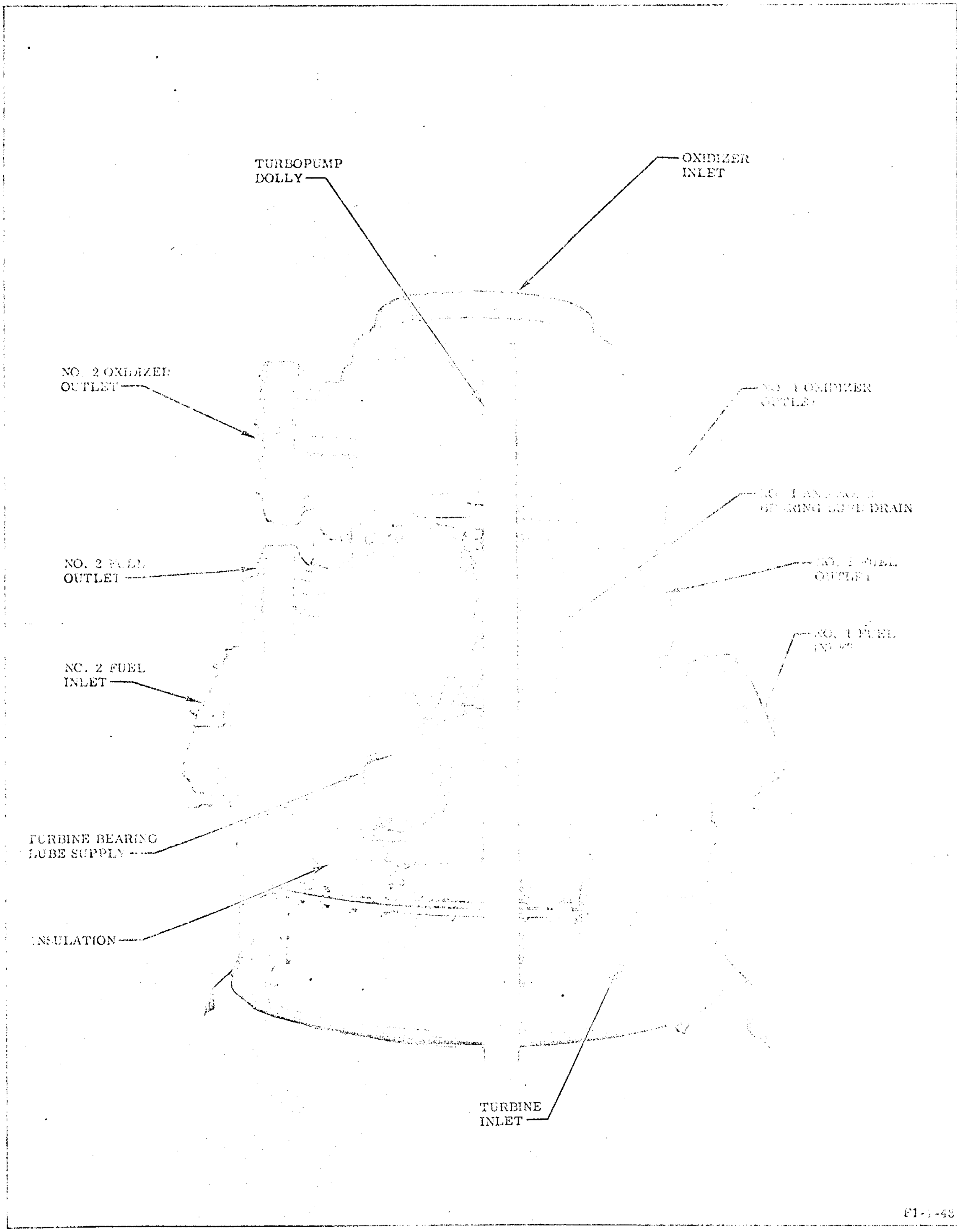


Figure I-13. Turbopump (Inboard)

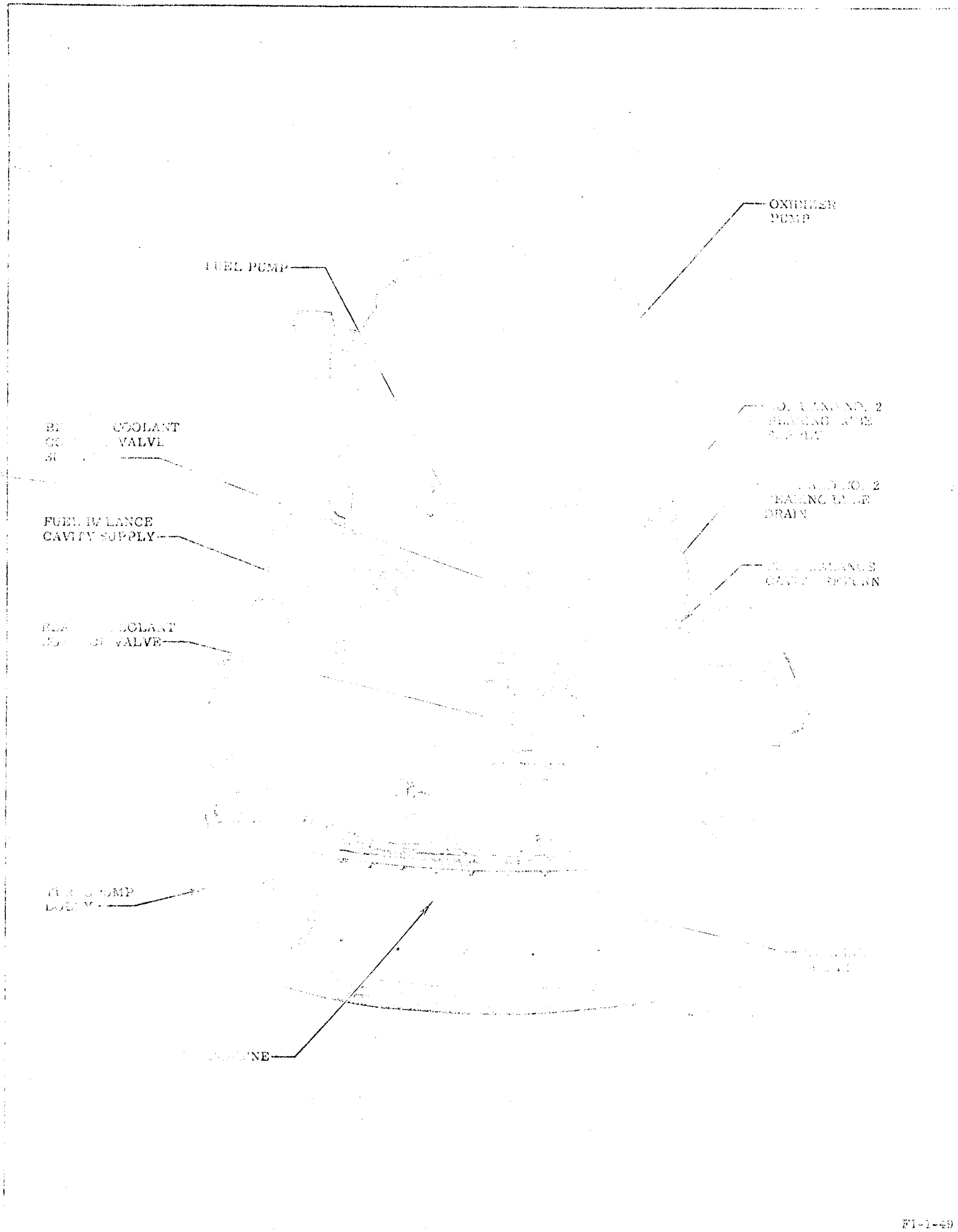


Figure 1-14. Turbopump (Outboard)

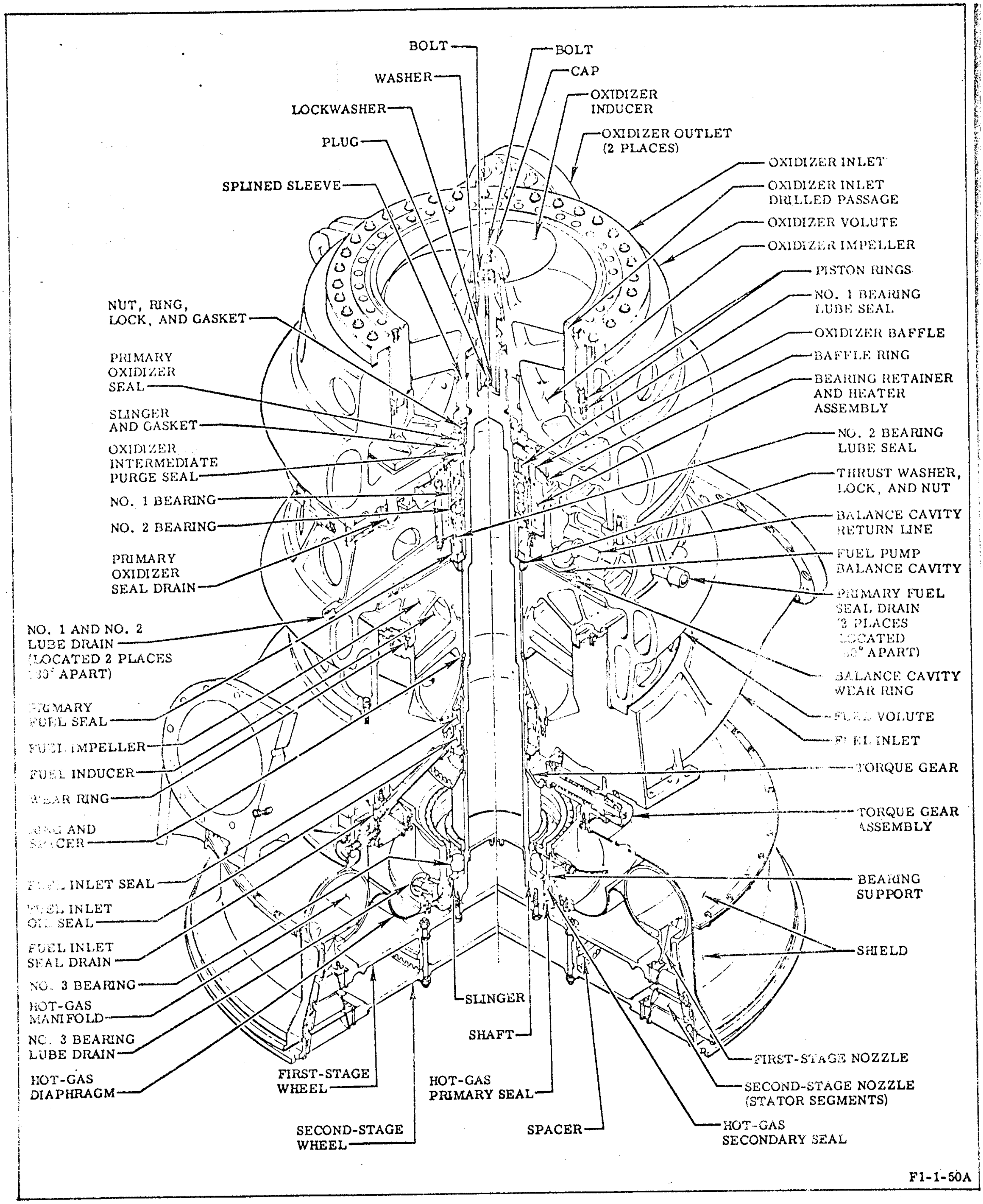


Figure 1-15. Turbopump Cutaway

1-26. The turbopump contains a balancing system to control the axial thrust loads imposed upon the shaft and ball bearing assemblies by the forces primarily generated by the differential pressure across the oxidizer impeller. The balancing system utilizes the area between the back of the fuel impeller and fuel volute as a balance cavity, to which fuel pressure from the discharge side of the fuel pump is directed and regulated, to partially counterbalance the axial thrust developed by the oxidizer impeller. Manual rotation of the turbopump shaft for the purpose of facilitating turbopump preservation and detecting excessive breakaway and running torque, is provided by a ring and pinion gear combination. The ring gear is splined to the turbopump shaft, and the pinion gear is mounted to the torque gear housing in a spring-loaded, disengaged position. When manual rotation of the pump shaft is required, the pinion gear is pushed in to engage with the ring gear and a rotating force applied. The sleeve of the ring gear contains two holes, spaced 180 degrees apart, which are used in conjunction with a magnetic transducer for monitoring shaft speed during engine operation.

1-27. The turbopump bearings are cooled by pressurized fuel supplied through a bearing coolant control valve to spray nozzles at the bearings. The fuel is routed in parallel from the coolant control valve to the No. 1 and No. 2 bearings and to the No. 3 bearing and is then drained overboard through the fuel overboard drain system. On engines incorporating MD145 change, the parallel routing from the bearing coolant control valve has been replaced by a series system. This change directs the drainage from the No. 1 and No. 2 bearings to splash-lubricate the No. 3 bearing and then overboard through the overboard drain system. Two cal-rod heaters, cast into the retainer block of the No. 1 and No. 2 bearings, prevent condensation and ice from forming on the bearings during engine standby.

1-28. The principal sections of the turbopump consist of an oxidizer pump section, a fuel pump section, and a turbine section. The three sections are structurally connected to each other by pins, which permit relative radial movement to compensate for the effects of thermal differences between the oxidizer, fuel, and turbine sections. A bearing coolant control valve mounted on the fuel pump section supplies coolant fuel to the bearings contained within the oxidizer pump and turbine sections. (See figure 1-16 for turbopump leading particulars.)

Weight (average)	3,150 lb
Length	5 ft
Diameter	4 ft
Shaft speed	5,492 rpm
Oxidizer pump inlet pressure	65 psia
Oxidizer pump discharge pressure	1,502 psia
Oxidizer pump flowrate	3,986 lb/sec (25,063 gpm)
Fuel pump inlet pressure	45 psia
Fuel pump discharge pressure	1,870 psia
Fuel pump flowrate	1,[illegible] lb/sec (15,820 gpm)
Turbine inlet temperature	[illegible]53° F
Turbine inlet pressure	[illegible]5 psia total
Turbine exit pressure	5[illegible] psia
Turbine brake horsepower	5[illegible],146 bhp
Bearing coolant flowrate (parallel system)	[illegible].5 gpm
Bearing coolant flowrate (series system)	3.[illegible] gpm
Shaft breakaway and running torque	20 ft lb max.

Figure 1-16. Turbopump Leading Particulars (Engines Incorporating MD[illegible] or MD174 Change)

1-29. TURBOPUMP OXIDIZER PUMP DESCRIPTION. The principal parts of the oxidizer pump (figures 1-17 and 1-18) are an inducer, an impeller, a volute, two bearings, and the necessary seals to contain the oxidizer and coolant fuel within their respective areas of the oxidizer pump section. The inducer is splined to the shaft and increases the oxidizer inlet pressure to prevent cavitation and to direct the oxidizer into the inlet of the impeller. The impeller is installed on the shaft through an internally/externally splined coupler and imparts velocity to the fluid. The volute houses and supports the component parts of the oxidizer pump and converts the kinetic energy of fluid velocity to potential energy of fluid pressure. The oxidizer volute incorporates a ring that is pinned within a recess of the volute by 36 radially inserted pins. The fuel volute attaches to this ring by 36 bolts that are axially installed in threaded holes of the ring. Two discharge ports supply oxidizer to respective inlets of the oxidizer dome and manifold assembly. The bearings at the oxidizer pump section (figure 1-16), identified as No. 1 and No. 2 bearings, are a matched set of ball bearings that support the shaft at its forward end and absorb shaft axial loads.

1-31. Four major seals are contained in the oxidizer pump section. No. 1 seal (primary oxidizer seal) is a carbon-nose-to-mate-ring seal that seals the oxidizer propellant area from the bearing coolant fluid area. Leakage past this seal is directed overboard through the oxidizer overboard drain line. No. 2 seal (intermediate oxidizer seal) is a carbon-segmented seal with two spring-loaded carbon segments riding on the pump shaft and is a backup seal to [illegible] the oxidizer from the fuel coolant. A nitrogen gas purge is applied between the two segment layers and flows axially in both directions between the faces of the carbon segments and the shaft. Because carbon seals are primarily dynamic seals, the purge acts as a positive pressure barrier to isolate the oxidizer and bearing coolant from each other under static conditions. The purge flow to the oxidizer side of the seal is directed overboard through the same line that drains the primary oxidizer seal cavity.

1-31A. No. 3 seal (No. 1 bearing lube seal) is a carbon-nose-to-mate-ring seal, which is the forward seal to confine the bearing coolant fluid within the bearing retainer and heater assembly. Leakage past No. 3 seal, along with the purge gas flowing from the coolant side of the intermediate oxidizer seal, is directed overboard by the nitrogen purge overboard drain line. No. 4 seal (No. 2 bearing lube seal) is a carbon-nose-to-mate-ring seal, which is the rear seal to confine the bearing coolant fluid within the bearing retainer and heater assembly. Leakage past No. 4 seal is directed to the fuel drain manifold by the primary fuel seal drain lines. Additional seals of the oxidizer pump section include two KEL-F coated, CRES, split piston rings, a Teflon-coated Naflex seal, and KEL-F wear-ring seal. The split piston rings recess into grooves of the oxidizer inlet and seal the interface of the oxidizer inlet skirt and volute wall. Any leakage past both seals is directed back to the inlet side of the pump [illegible] passages drilled in the [illegible] Naflex seal is [illegible] flanges of the oxidizer [illegible] volute. The [illegible] seal attached to the [illegible] ring effectively [illegible] the pump from the [illegible] by placing a series of orifices [illegible] between the two sides. [illegible] bearing retainer [illegible]

1-32. TURBOPUMP [illegible] ION. The principal [illegible] (figures 1-17 and [illegible]), inducer, an [illegible] energy sends to [illegible] fuel section of the pump [illegible] is [illegible] inducer. The [illegible] fuel volute [illegible] housing on the bottom [illegible] on the turbine section are [illegible] assembly to provide the primary structural interface between the fuel pump [illegible] turbine section. The inducer [illegible] the shaft and increases the [illegible] to prevent cavitation and [illegible] into the eye of the impeller. The impeller [illegible] to the shaft and imparts [illegible] The volute converts the [illegible] velocity to potential energy [illegible] six bolts connect the fuel volute to [illegible] of the oxidizer volute to provide the [illegible] structural interface between the fuel pump section and the oxidizer pump section. The fuel volute incorporates two discharge [illegible] supply fuel to the respective inlets of the [illegible] fuel inlet manifold.

1-33. Three major seals are contained in the fuel pump section: No. 5, No. 6, and No. 7 seals. No. 5 seal (primary fuel seal) is a carbon-nose-to-mate-ring seal, which seals the shaft area of the balance cavity. Any leakage past this seal, along with any leakage past the No. 4 seal, is directed to the fuel drain manifold by the primary fuel seal drain lines. No. 6 seal (fuel inlet seal) is a carbon-nose-to-mate-ring seal and seals against leakage from the fuel inlet. Any leakage past this seal is directed to the fuel drain manifold by the fuel inlet seal drain lines.

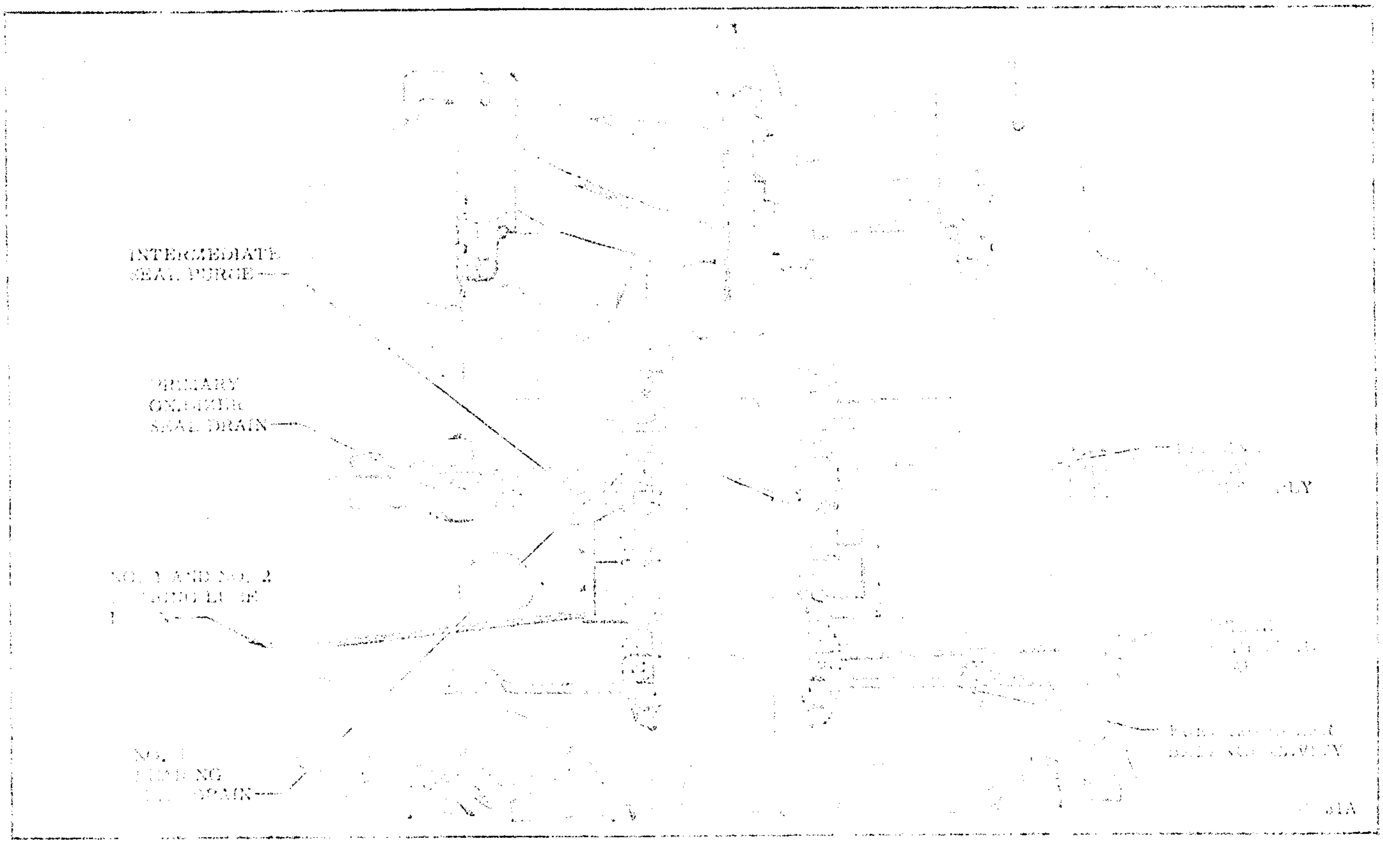


Figure 1-17. Oxidizer Pump and Fuel Pump

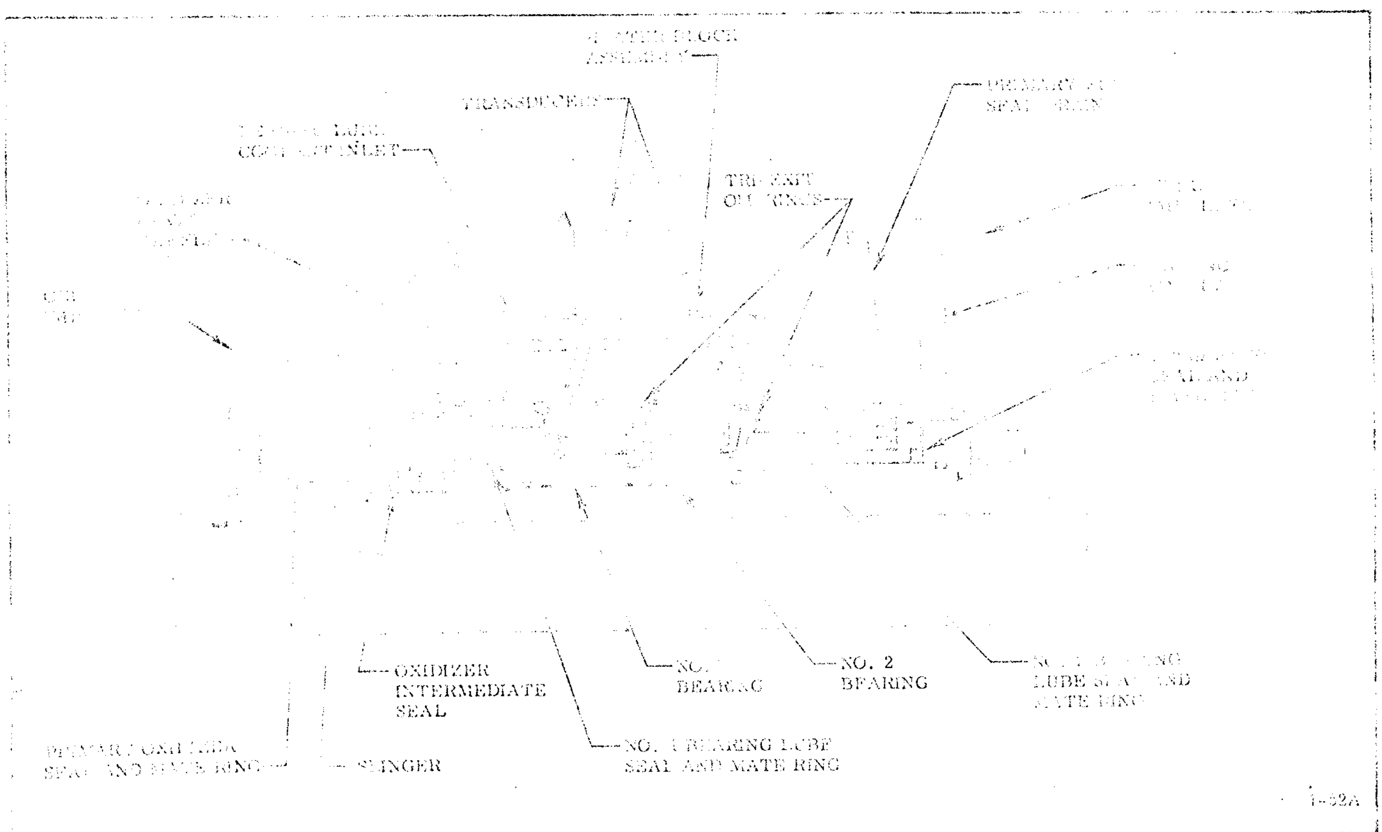


Figure 1-18. Oxidizer Pump and Fuel Pump Bearings

1-34. No. 7 seal (fuel lube seal) is a carbon-nose-to-mate-ring seal and prevents leakage of [illegible] fuel from the bearing support area. Any leakage past No. 7 seal would be directed to the fuel drain manifold, along with any leakage past the No. 6 seal, by the fuel inlet seal drain lines. Additional seals of the fuel pump section include three synthetic rubber O-rings and two lead-[illegible] rings. Two of the synthetic [illegible] seal [illegible] of the fuel inlet [illegible] of the volute [illegible] other O-ring seals [illegible] interface [illegible] gear housing and fuel [illegible]. One of the wear rings, which is a [illegible]-type [illegible] bolted to the fuel inlet [illegible] seals the high-pressure [illegible] the pump from the low-pressure side [illegible] a series of orifices and expansion [illegible] between the two sides. The other wear ring, which is bolted [illegible] volute and extends into a groove in the [illegible] of the impeller, is a labyrinth-type seal and, in conjunction with the primary fuel seal, establishes the outer and inner diameters of the fuel balance cavity.

1-35. TURBOPUMP TURBINE DESCRIPTION. The principal parts of the turbine section are the turbine inlet manifold, two turbine wheels, one bearing, and the necessary seals to contain the hot gas within the turbine section. (See figure 1-19.) The turbine inlet manifold houses the component parts of the turbine section and incorporates six spools to provide the structural interface between the turbine section and the fuel pump section. Each spool has an individually matched clevis fitting, which bolts to the [illegible] pump inlet, and a clevis pin, which are identified with the manifold serial number and a [illegible] number corresponding to the spool position [illegible] which they are matched.

1-36. The turbine manifold incorporates an inlet flange to which the gas generator combustor [illegible] attached and [illegible] outlet flange for the attachment [illegible] the heat exchanger. A nozzle assembly [illegible] to the [illegible] manifold directs the gas generator gases onto the blades of the first-stage turbine wheel, and 40 nozzle segments bolted to the inlet manifold direct gases from the first-stage turbine onto the blades of the second-stage turbine wheel.

1-37. Each turbine wheel consists of a disc incorporating a series of fir tree slots in its outer periphery into which blades are inserted and riveted in place. The first-stage wheel is bolted to and interfaces with the main shaft through curvic coupling that absorbs the high shear loads experienced during engine start. The second-stage wheel is bolted to the first-stage wheel through a [illegible] curvic coupler spacer. The bearing in the turbine section is identified as the No. 3 bearing and is a roller bearing that supports the main shaft at the turbine end and absorbs radial loads imposed on the shaft. The bearing is supported by the turbine bearing [illegible] assembly, which is bolted to the torque [illegible] housing and the turbine inlet manifold assembly.

1-38. Two major seals are [illegible] in the turbine section: No. 8 and No. 9 seals. No. 8 seal (hot-gas secondary seal) and No. 9 seal (hot-gas primary seal) are both carbon segmented seals with the spring-loaded segments riding against the pump shaft. The seals isolate the turbine section hot gases from the No. 3 bearing. Other seals in the turbine section consist of two pressure-actuated [illegible] and a honeycomb seal. One of the pressure-actuated seals, which is installed at the inlet [illegible] the hot-gas secondary seal housing and [illegible] bearing support assembly, seals [illegible] coolant fluid into the [illegible]. The other pressure-actuated [illegible] at the [illegible] of the bearing support assembly and the turbine inlet [illegible] seals against leakage [illegible] turbine inlet manifold. The [illegible] honeycomb [illegible] inner wall of the [illegible] at the area of the first-stage turbine wheel [illegible] in conjunction with [illegible] on the turbine wheel blades is a [illegible]-type seal that effectively prevents [illegible] of gas around the periphery [illegible].

1-39. BEARING COOLANT CONTROL VALVE DESCRIPTION. The bearing [illegible] control valve (figure 1-20) controls the coolant fuel flow to the turbopump bearings [illegible] means of supplying preservative [illegible] to the bearings. It is a normally closed [illegible] pressure-actuated poppet [illegible] redundancy to assure [illegible] coolant fluid. The valve assembly [illegible] coolant and one preservative-oil [illegible], three 40-micron filters [illegible] the coolant fuel, and [illegible] a quick-disconnect for [illegible] the preservative-oil supply line. The [illegible] coolant poppets offseat when fuel pump discharge pressure reaches a nominal 2[illegible] psig and directs th[illegible]

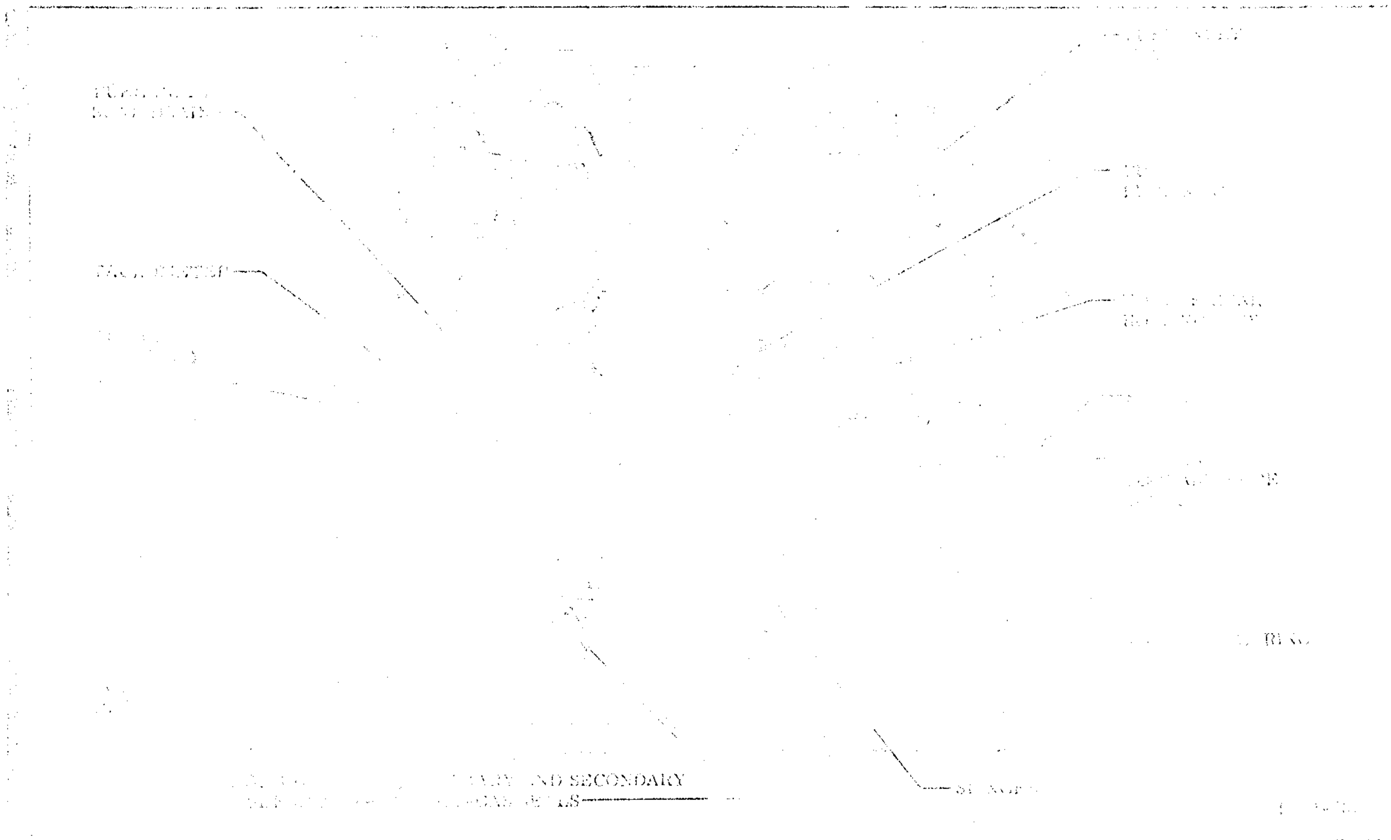


Figure 1-19. Fuel Pump Turbine

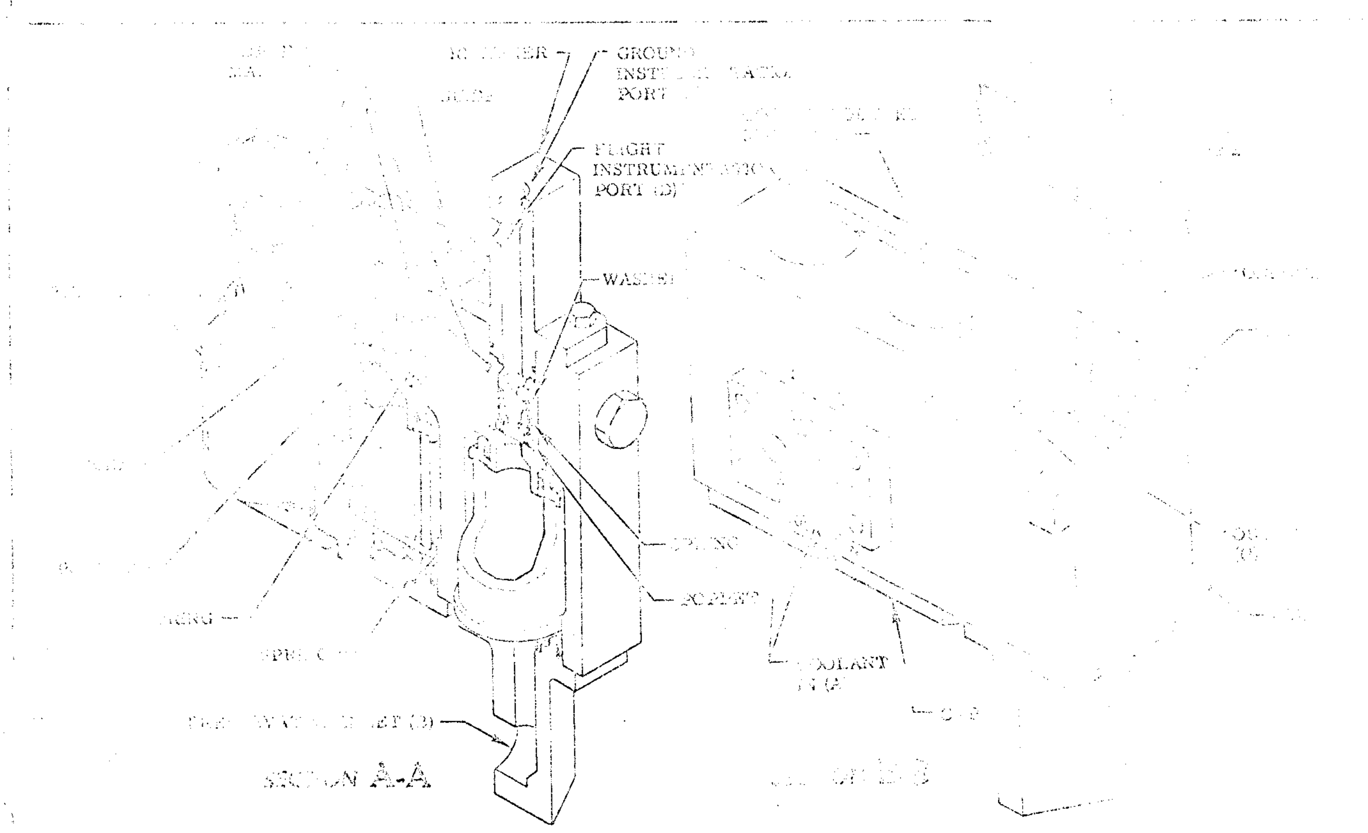


Figure 1-20. Bearing Coolant Control Valve

coolant through the restrictor to the turbopump bearings. The restrictor is sized during engine acceptance testing to provide a bearing pressure of 200-540 psig. The preservative-oil poppet offseats during preservation procedures at 9-20 psig and directs the preservative oil to the turbopump bearings. On engines incorporating MD145 change, the port for the turbine bearing jet ring is capped and the orifice is changed to accommodate the series lube system.

1-40. TURBOPUMP FUEL INLET ELBOW DESCRIPTION. The turbopump fuel inlet elbows No. 1 and No. 2) are single-inlet, dual-outlet elbows incorporating internal flow vanes. Fuel flows radially into the fuel pump inlet assembly from the two inlet elbows mounted 180 degrees apart. Lifting studs are provided on the elbows for ease of handling. Seal monitoring ports are provided on the downstream outlet flanges. One attach point for support of the engine interface panel is located on each elbow, and attach points are located on the duct side of the elbow for fastening a flexible (rubber) thermal insulation boot around the blow to the engine interface panel. The No. 2 elbow has a flanged attach point for the checkout valve engine return hose.

1-41. OXIDIZER VALVE DESCRIPTION.

1-42. The engine has two identical oxidizer valves (figure 1-21) that direct the flow of liquid oxygen to the thrust chamber and the flow of hydraulic control opening fluid to the gas generator control valve. The oxidizer valves are hydraulically actuated, spring-loaded closed, pressure-balanced, fail-to-the-run position, poppet-type valves having quick response and low delta-P operating characteristics. An integral part of each oxidizer valve, and mechanically opened by this valve, is a normally closed sequence valve which, in the open position, directs hydraulic control fluid to the opening port of the gas generator control valve.

1-43. The oxidizer valve is designed so that when it is in the open position, at rated engine oxidizer pressure and flowrate, it will not close if hydraulic control fluid opening pressure is lost. The oxidizer valve consists of a housing that contains the oxidizer inlet and outlet ports and the seat for the poppet seal; a poppet with a machined Teflon seal secured by a seal retainer; a cover that attaches to the valve housing and contains the two poppet-closing springs and also serves as a mount for the cylinder and a guide for the piston rod; a cylinder, within which the actuating piston operates, that contains the open and closed actuator ports and supports the position indicator drive shaft; a cylinder head that contains the inlet and outlet ports of the sequence valve and also provides a mount for the sequence valve gate; and a tapered piston rod that connects the actuator to the poppet, mechanically opens the sequence valve, and actuates the position indicator.

1-44. The sequence valve is a spring-loaded gate valve that seats against, and is hinged to, the oxidizer valve cylinder head. The sequence valve is offseated by the piston rod to direct opening hydraulic control fluid to the gas generator control valve when the oxidizer valve reaches 16.4 percent of its open position. The position indicator consists of a rotary-motion variable resistor and open and closed position switches. The position indicator is mounted on the oxidizer valve cylinder and is coupled to the indicator drive shaft, which is mechanically linked to the piston rod. The position switch provides relay logic in the engine electrical control circuit, and the variable resistor provides instrumentation for recording valve poppet movement.

1-45. Each oxidizer valve incorporates an oxidizer dome purge check valve to admit gaseous nitrogen downstream of the valve poppet to purge the thrust chamber oxidizer dome. The check valve is a gate-type valve, spring loaded to the closed position and allows flow in one direction when the differential pressure across the valve exceeds 5.0 psi. Five types of seals are used in the oxidizer valve: machined Teflon seals, Mylar lip seals, Teflon-coated steel Naflex seals, and Buna-N O-rings. Oxidizer valve leading particulars are listed in figure 1-22.

1-46. FUEL VALVE DESCRIPTION.

1-47. The engine has two identical fuel valves (figure 1-23) to direct fuel to the thrust chamber. The valves are hydraulically operated, spring-loaded-closed, pressure-balanced, fail-to-the-run-position, poppet-type valves having quick

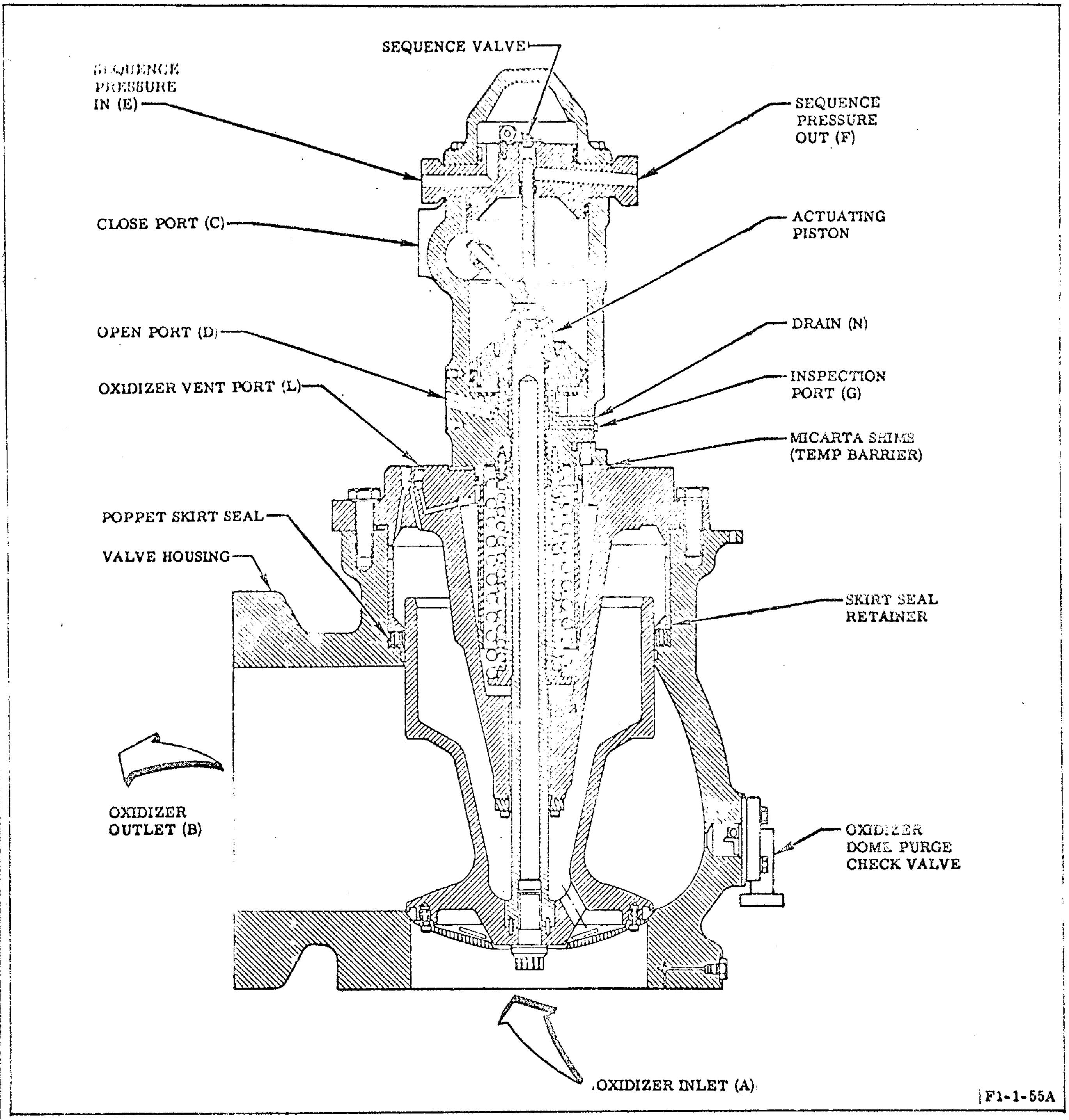


Figure 1-21. Oxidizer Valve

response and low delta-P operating characteristics. The fuel valve is designed so that when it is in the open position, at rated engine fuel pressure and flowrate, it will not close if hydraulic control fluid opening pressure is lost.

1-48. The fuel valve consists of a housing containing fuel inlet and outlet ports, closing and opening ports, a drain port, a purge port, a poppet seal seat and retainer, a spring-loaded poppet with a machined Teflon seal secured by a seal retainer, an actuator guide internally drilled to provide the open port passage, and a piston that connects to the poppet. The nose seal retainer incorporates 12 radially drilled passages to direct fuel into the balance cavity

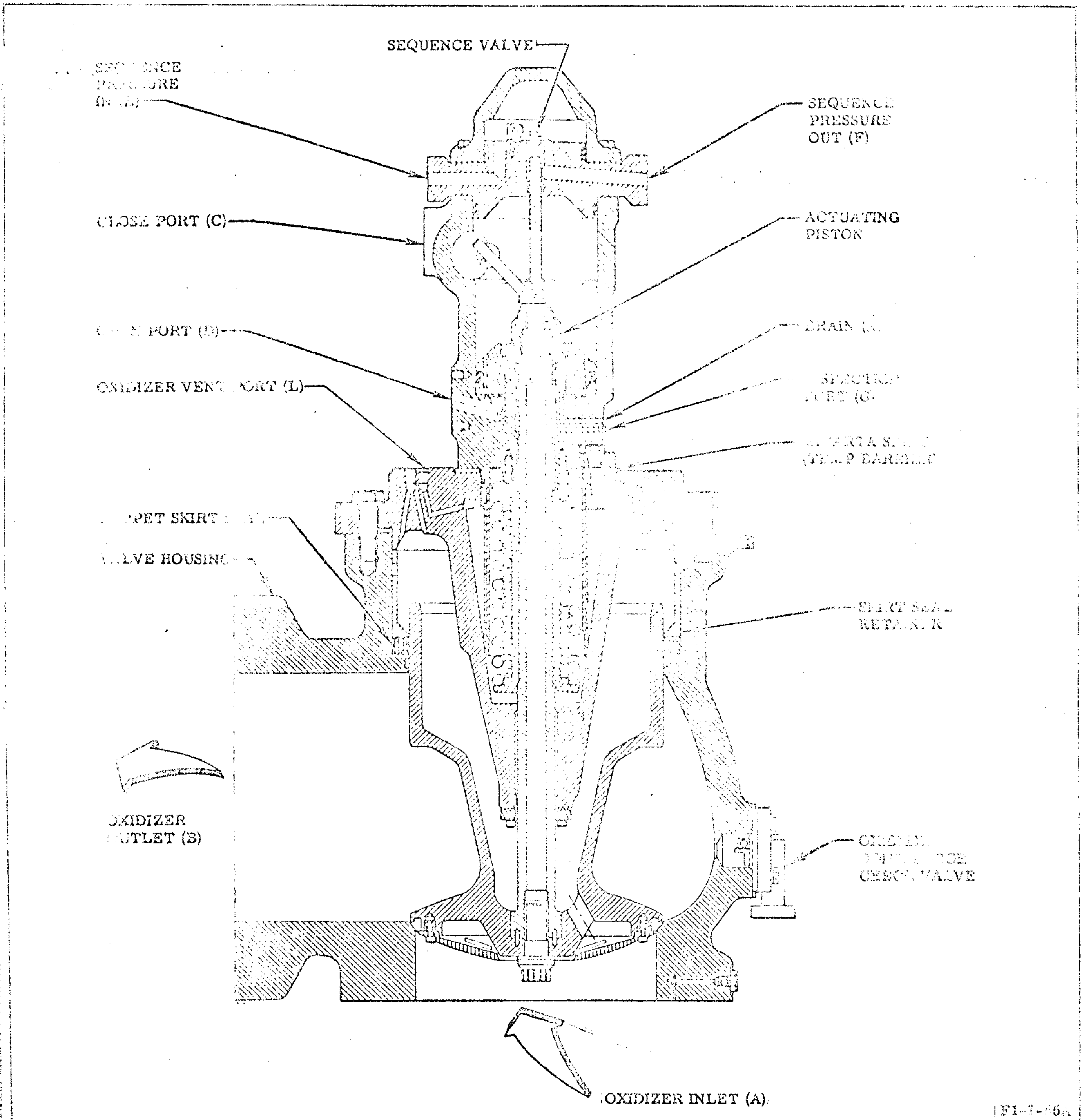


Figure 1-21. Oxidizer Valve

response and low delta-P operating characteristics. The fuel valve is designed so that when it is in the open position, at rated engine fuel pressure and flowrate, it will not close if hydraulic control fluid opening pressure is lost.

1-48. The fuel valve consists of a housing containing fuel inlet and outlet ports, closing and opening ports, a drain port, a purge port, a poppet seal seat and retainer, a spring-loaded poppet with a machined Teflon seal secured by a seal retainer, an actuator guide internally drilled to provide the open port passage, and a piston that connects to the poppet. The nose seal retainer incorporates 12 radially drilled passages to direct fuel into the balance cavity during the last portion of valve closing travel. This feature assists the valve in closing by maintaining a positive fluid pressure within the balance cavity. A position indicator attaches to the valve housing and recesses into the piston shaft. The indicator consists of a linear-motion variable resistor and open and closed position switches. The position switches provide relay logic in the engine electrical control circuit, and the variable resistor provides instrumentation for recording valve poppet movement. Three types of seals are used in the fuel valve: machined Teflon seals, Viton-A O-rings, and Buna-N O-rings. Fuel valve leading particulars are listed in figure 1-22.

	Oxidizer Valve	Fuel Valve
Weight	168.0 lb	90.0 lb
Length	30.0 in.	16.0 in.
Width	17.25 in.	11.0 in.
Opening pressure	200 psig max.	110 psig max.
Closing pressure	75 psig max.	0 psig (spring only)
Opening time (switch times)	320 msec	635 msec
Closing time (switch times)	325 msec	930 msec
Inlet diameter	8.0 in.	6.0 in.
Outlet diameter	8.0 in.	6.0 in.
Poppet travel	2.34 in.	2.0 in.
Poppet seal	Teflon	Teflon

Figure 1-22. Oxidizer Valve and Fuel Valve Leading Particulars

1-49. OXIDIZER HIGH-PRESSURE DUCT DESCRIPTION.

1-50. The oxidizer high-pressure ducts contain and distribute the oxidizer separately to each of the oxidizer valves and also provide support for the forward end of the turbopump. The ducts are constructed of drawn aluminum tubing, bent in a continuous section. This design provides flexibility to compensate for expansion, contraction, and vibration. Each duct requires a custom spacer at each end. These spacers are machined for a particular engine and are not interchangeable. On engines incorporating MD137 change, the custom spacers are replaced with selective spacers machined to various dash number sizes. A tap-off flange for the gas generator oxidizer duct is provided on the No. 2 oxidizer high-pressure duct.

1-51. FUEL HIGH-PRESSURE DUCT DESCRIPTION.

1-52. The fuel high-pressure ducts contain and distribute the fuel separately to each of the fuel valves and support the forward end of the turbopump. The construction and design of the fuel ducts provide flexibility to compensate for expansion, contraction, and vibration. Each duct requires a custom spacer at each end. On engines incorporating MD137 change, the custom spacers are replaced by selective spacers with various dash number sizes. Tap-offs for the bearing coolant control valve, gimbal filter manifold, igniter fuel valve, and fuel high-pressure duct drain quick-disconnect are provided on the No. 1 fuel high-pressure duct. Tap-offs for the gas generator fuel duct, engine control valve, No. 2 fuel bleed and fuel high-pressure duct drain quick-disconnect are provided on the No. 2 fuel high-pressure duct.

1-53. ENGINE INTERFACE PANEL DESCRIPTION.

1-54. The engine interface panel (figure 1-24) is mounted above the turbopump oxidizer and fuel inlets. The panel contains the customer connect locations for electrical connectors between the engine and the vehicle. The panel also provides an attach point for thermal insulation attach brackets.

1-55. IGNITION SYSTEM DESCRIPTION.

1-56. The engine ignition system supplies heat energy to initiate combustion in the gas generator combustor, thrust chamber nozzle extension, and the thrust chamber. Five igniters are required for each engine start: two pyrotechnic igniters for the gas generator, two pyrotechnic igniters for the thrust chamber nozzle extension, and a hypergol igniter for the thrust chamber. The pyrotechnic igniters are electrically fired by 500 vac. The pyrotechnic igniters initiate combustion of the fuel and oxidizer in the gas generator and reignite the fuel-rich gas generator exhaust gas in the nozzle

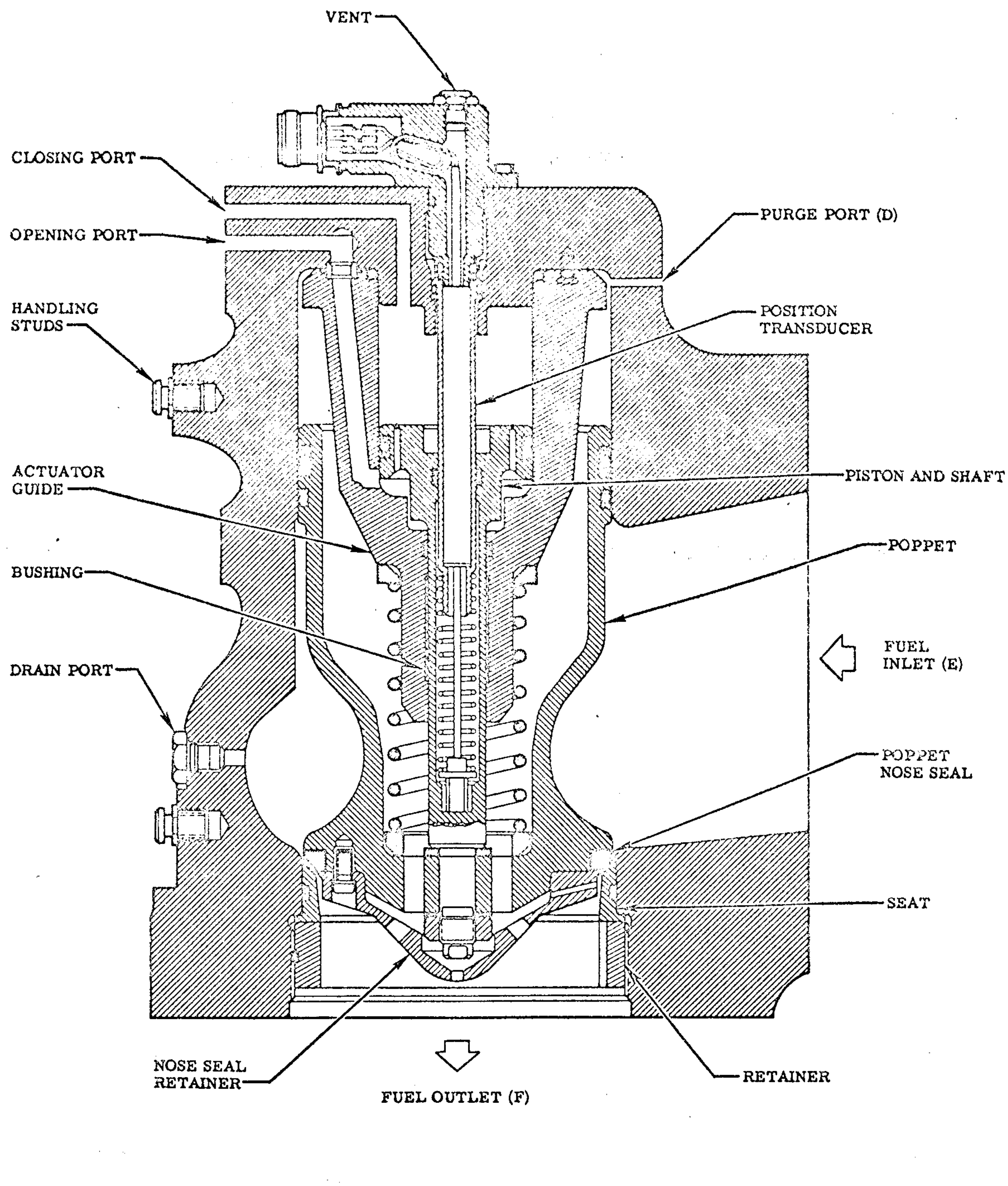


Figure 1-23. Fuel Valve

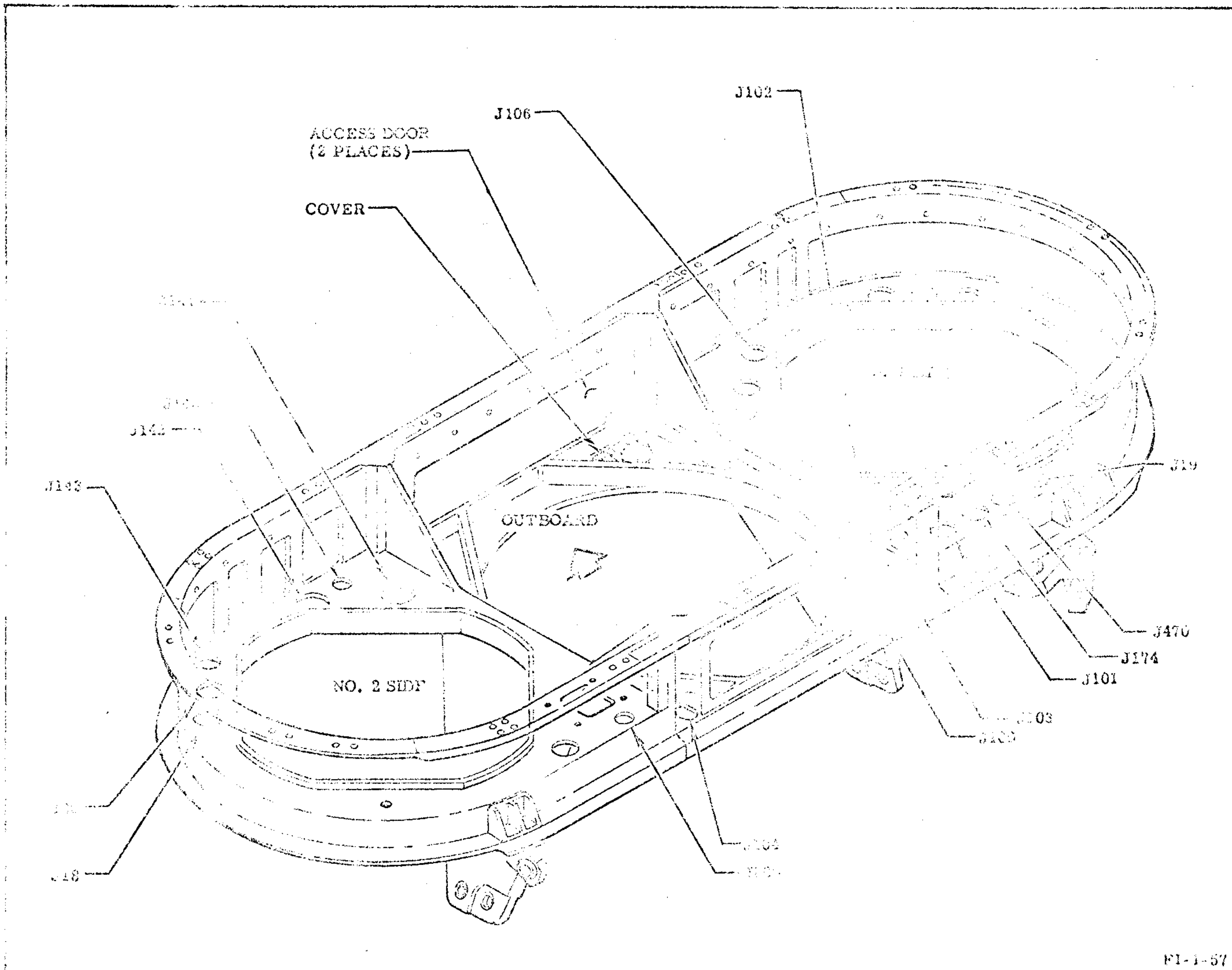


Figure 1-24. Engine Interface Panel

extension. The hypergol igniter initiates combustion in the thrust chamber when fuel pressure from the No. 1 fuel high-pressure duct ruptures the hypergol igniter diaphragms and forces pyrophoric fluid into the thrust chamber through the igniter fuel orifices in the injector.

1-57. HYPERGOL IGNITER DESCRIPTION.

1-58. The hypergol igniter (figure 1-25) contains the pyrophoric fluid that produces initial combustion in the thrust chamber. The igniter is installed in the hypergol manifold by a threaded cap secured by a lockpin. The igniter consists of a cartridge, a plug, a cap, and related seals. The cartridge contains 403 ±10 grams of pyrophoric fluid consisting of 85 percent triethylborane and 15 percent triethylaluminum. Two burst diaphragms are provided in the cartridge, one at each end to contain the pyrophoric fluid within the cartridge. The burst diaphragm at the cap end of the igniter is identified as the downstream diaphragm and has a burst pressure of 350 (+25, -75) psig. The upstream diaphragm has a burst pressure of 500 (+25, -75) psig. The hypergol igniter is approximately 18 inches in length and 2-3/8 inches in diameter.

1-59. PYROTECHNIC IGNITER DESCRIPTION.

1-60. The pyrotechnic high-voltage igniters (figure 1-26) initiate combustion in the gas generator and reignite the fuel-rich turbine exhaust